UNIVERSITAT POLITÈCNICA DE VALÈNCIA

PhD Programme in Water and Environmental Engineering

PhD Thesis

A sectorial Analysis of Municipal Water Consumption and Management in Saudi Arabia

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ABSTRACT

The Kingdom of Saudi Arabia is undergoing substantial economic, industrial, commercial, and population growth. This growth, in turn, leads to increased water demand in the region. In addition to population growth, industrialization and modernization have placed increasing pressure on KSA's water infrastructure. There is an urgent need to increase the water capacity to meet the projected demand and maintain the water systems' security and reliability. Therefore, it is imperative to find solutions that improve the efficiency of the Kingdom's water system. A key element in this effort is understanding and classifying how water is consumed with its micro-components within various segments.

The thesis aims to collect precise knowledge about municipal water consumption patterns and trends to understand water consumption patterns and consumer behaviours better and develop preliminary estimates and assumptions. This will drive the municipal water demand model in KSA to be capable of dealing with different scenarios and constraints.

The development of the municipal water demand model highlighted the need for reliable statistical and water billing data. These form the starting point of the forecast and need to be available at a high enough resolution. The model provides a framework for the required data to be built on further. The analysis results will also determine the drivers and categories used in the model.

The model focuses on the non-Residential water demand. Still, separate forecasts are included for the residential category to enable the extrapolation of the results and downward analysis for a more accurate and cost-effective bottom-up approach to forecasting and an overall better understanding of the population's water consumption behaviours.

RESUMEN

El Reino de Arabia Saudí está experimentando un importante crecimiento económico, industrial, comercial y demográfico. Este crecimiento, a su vez, provoca un aumento de la demanda de agua en la región. Además del crecimiento demográfico, también la industrialización y la modernización han ejercido una presión cada vez mayor sobre las infraestructuras hídricas del país. Urge aumentar la disponibilidad de agua para satisfacer la demanda prevista y mantener la seguridad y fiabilidad de los sistemas hídricos. Por lo tanto, es imperativo encontrar soluciones que mejoren la eficiencia del sistema hídrico del país. Un elemento clave en este esfuerzo es comprender y clasificar cómo se consume el agua con sus microcomponentes dentro de varios segmentos.

La tesis recopila conocimientos precisos sobre las pautas y tendencias del consumo municipal de agua para comprender mejor los patrones de consumo y los comportamientos de los consumidores, así como desarrollar estimaciones e hipótesis preliminares. De este modo, se impulsará el modelo de demanda de agua municipal en el país para que sea capaz de hacer frente a diferentes escenarios y limitaciones.

El desarrollo del modelo municipal de demanda de agua ha mostrado la necesidad de disponer de datos estadísticos y de facturación del agua fiables. Éstos constituyen el punto de partida de la previsión y deben estar disponibles con una resolución suficientemente alta. El modelo aquí presentado proporciona un marco para que nuevos desarrollos futuros. Los resultados del análisis también determinarán los factores y categorías utilizados en el modelo.

El modelo se centra en la demanda de agua no residencial. No obstante, se incluyen previsiones separadas para la categoría residencial a fin de permitir la extrapolación de los resultados y el análisis top-down para un enfoque más preciso de las previsiones y, también, para una mejor comprensión general de los comportamientos de consumo de agua de la población.

RESUM

El Regne de l'Aràbia Saudita està experimentant un important creixement econòmic, industrial, comercial i demogràfic. Aquest creixement, al seu torn, provoca un augment de la demanda d'aigua a la regió. A més del creixement demogràfic, també la industrialització i la modernització han exercit una pressió cada vegada major sobre les infraestructures hídriques del país. Urgeix augmentar la disponibilitat d'aigua per a satisfer la demanda prevista i mantindre la seguretat i fiabilitat dels sistemes hídrics. Per tant, és imperatiu trobar solucions que milloren l'eficiència del sistema hídric del país. Un element clau en aquest esforç és comprendre i classificar com es consumeix l'aigua amb els seus microcomponents dins de diversos segments.

La tesi recopila coneixements precisos sobre les pautes i tendències del consum municipal d'aigua per a comprendre millor els patrons de consum i els comportaments dels consumidors, així com desenvolupar estimacions i hipòtesis preliminars. D'aquesta manera, s'impulsarà el model de demanda d'aigua municipal al país perquè siga capaç de fer front a diferents escenaris i limitacions.

El desenvolupament del model municipal de demanda d'aigua ha mostrat la necessitat de disposar de dades estadístiques i de facturació de l'aigua fiables. Aquests constitueixen el punt de partida de la previsió i han d'estar disponibles amb una resolució prou alta. El model ací presentat proporciona un marc perquè nous desenvolupaments futurs. Els resultats de l'anàlisi també determinaran els factors i categories utilitzats en el model.

El model se centra en la demanda d'aigua no residencial. No obstant això, s'inclouen previsions separades per a la categoria residencial a fi de permetre l'extrapolació dels resultats i l'anàlisi *top-*down per a un enfocament més precís de les previsions i, també, per a una millor comprensió general dels comportaments de consum d'aigua de la població.

INTRODUCTION

PRESENTATION

Suppose you want to decide how best to evaluate the water consumption of specific items. In that case, a municipal water demand model approach is appropriate, where each user's water consumption is considered item-by-item. As a result, water producers may not struggle when deciding how much water a specific user demands. It can start with micro-components water consumption. Each micro- component of water consumption presents its consumption. The totals are added together to form the big picture. The parts are used to create a demand for the entire user. It goes from the specific to the general. With this approach, you aggregate low-level items and demand them together. You can then apply an allocation scheme to break down that high-level demand into lower-level components and vice versa.

This approach looks at extensive and detailed water consumption information. You can forecast each low-level water consumption micro-components separately or combine them together. Then, you sum the individual forecasts into group-level forecasts for a higher-level view. It also provides the most accurate estimates at the item level and therefore is a go-to method for micro-components. The downside is that many users lack sufficient data to reveal patterns or produce accurate predictions in isolation. The model accuracy is achieved by increasing the volume of data. This volume helps reduce “noise” (random variation) and reveals undetectable patterns at the individual-item level. Also, this approach is helpful and works well in planning and water conservation programs.

One of the benefits of a municipal water demand model approach is that it offers more understanding of the water conservation process and improves water producers, consumers, and regulators' efficiency. It also allows water producers and consumers to examine water consumption operations and assess spending. It also allows the water regulators to develop a standard and KPIs and the governments to allocate budgets and target projects required to meet the demand.

The literature review is inconclusive regarding the most appropriate water forecasting approach model (Top-Down or Bottom-up) to determine water demand levels. This thesis presents the analytical results for developing a comprehensive and flexible municipal water demand model that can work following both approaches.

This paper aims to analyse municipal water consumption and develop a model for detecting water consumption under any conditions and with restricted information.

This research details the municipal water consumption model expressions for different segments with different options. It can be considered that the municipal water consumption model provides other water consumption models and options for each user regardless of information limitations.

Understanding that there is no way to predict the future is essential. However, you can apply methods to increase the likelihood of your forecast being realistic and flexible enough to adjust. It also encourages you to assess your current situation and capabilities and see where you can expect to go. So, the model's goal is to predict the demand and tell you what you need to know to take meaningful action in the present.

Developing a municipal water demand model enables the projection of micro-level water consumption inputs to reach the total water consumption for each segment to find its demand for a particular year. It helps to allocate water resources and make capital budgeting decisions more efficiently.

The analysis is based on micro factors, clearly showing the locations with higher water consumption. It is aware of the consumption occurring by each segment and whether it will be possible to reduce the water consumption and improve its efficiency.
A clear, detailed, and flexible model can help you anticipate your forecast portfolio. It will help you better understand where you must be and what it will take to get there.

STATE of THE ART AND JUSTIFICATION of THE THESIS

The Kingdom of Saudi Arabia (KSA) is located in the driest spot of the Middle East region, which is characterized by sweltering summers, dry winters (SGS 2012), and scarcity of water supply dating back to the early 1970s (Allan 1997 and UNDP 2013).

KSA has no continual rivers or lakes but has just one reliable natural water source supply type: groundwater (World Bank 2004; Ouda 2015). Moreover, tremendous socio-economic development has occurred in KSA during the last few decades due to revenues created from crude oil production (World Bank 2005, 2010; Nizami et al. 2015; Shahzad et al. 2016). This development has caused rapid increases in municipal, industrial, and agricultural water demands (Ouda et al. 2017), which will execute additional pressure on water resources and challenge the KSA's socioeconomic developmental plans (Ouda et al. 2016). As a result, the KSA has a significant water shortage problem where water demand far exceeds the water resource's sustainable yields. The Ministry of Environment, Water and Agriculture (MoWE), as the national water manager and planner, faces a myriad of complex issues, such as water scarcity, water security, unsustainable water use, water infrastructure rehabilitation, and planning for expansion (delivery and storage), availability of finance, lack of emergency preparedness and lack of regulation and government oversight.

There has been a steady increase in water consumption in the last few years, and the country's total water use has increased from approximately 17.8 billion cubic meters per year (BCM/year) in 2008 to around 26 BCM/year in 2018 (MoWE 2008 and MEWA 2018). During the same period, the water demand for the agricultural sector has increased from around 15 BCM/year to 21.2 BMC/year, while the industrial sector has increased from around 0.7 BMC/year to around 1.4 BMC/year, and the municipal has increased from around 2 BMC/year to around 3.4 BMC/year. In 2018, the agricultural sector consumed approximately 82% of the total water supplied.

In 2010, the total consumption of water resources for municipal, agricultural, and industrial was about 188 m^3/capita/year (Ouda et al. 2017). This number is lower than the 500 m3/capita/year limit the World Health Organization (WHO) puts for water-stress countries (Jagannathan et al. 2009 and UNDP 2013).

The KSA's water budget for 2012, including all-natural and anthropogenic inflows (including desalinated seawater) and outflows across the KSA boundary, is negative as the outflows exceed the inflows by 13.70 BCM. The deficit comprises about 1.6 million cubic meters (MCM) of inflows from desalination, which, if excluded, would increase the shortfall to approximately 15.2 BCM. The municipal water demand for 2012 was mainly satisfied with non-renewable groundwater, accounting for about 74% (15.45 BCM) of the total supply from various sources. Renewable water resources and desalinated water contributed approximately 17.5% (3.70 BCM) and 7.4% (1.54 BCM), respectively. The contribution from wastewater is minimal (around 1.1%).

Demand forecasting is a critical component of long-term planning for the water sector. On the one hand, accurate demand forecasts will ensure that the water supply installed capacity is sufficient to meet the future projected demand. On the other hand, they will minimize the possibility of overbuilding capacity, incurring unnecessary costs. Demand forecast also helps policymakers integrate water resources planning and conservation into the policies. Reliable water demand forecasting provides water sector managers (MEWA, NWC, SWCC) the ability to make sound decisions that will provide a basis for integrating the electricity generation and fuel demand for seawater desalination and water transmission into the overall planning process.

The total water demand for all the sectors combined is expected to increase to approximately 22.8 BCM annually, under the continuous water consumption in municipal, agricultural, and industrial demand forecast following a linear projection based on historical trends. The overall KSA water budget deficit will increase from 13.7 BCM/year in 2012 to 19 BCM/year in 2040 if no measures are implemented to reduce water consumption.

It should be noted that cumulative municipal water demand for the next 27 years (79 BCM) is less than 4% of non-renewable groundwater resources (2,360 BCM). In addition, it represents around 20% of expected cumulative agricultural water consumption (473 BCM for 2013-2040) if the agriculture consumption continues at approximately 17.5 BCM/year. This will result in a very high risk to the nation’s strategic water resources and leave future generations with no choice but to depend on costly and non-conventional water resources such as desalination and reclaimed water.

In the early 1970s, KSA's population was 7 million. By 2016 it had increased to around 32 million, with an average growth rate of 3.4% (Ismail & Nizami 2016; CDSI 2016 and Nizami et al. 2016). Civilization levels also increased from 50% to 80% over this period (CDSI 2010; Nizami et al. 2017; Ouda et al. 2014). Subsequently, the water demand across all KSA sectors increased significantly (Ouda 2014 and Abderrahman 2001). The water gap in 2010 between demand-supply was about 11.5 BCM, primarily associated with groundwater resource depletion (UNDP 2013).

Municipal water demand increased from 200 MCM in 1970 to 3,392 MCM in 2018. This annual growth rate is 6% (MWE, 2012; MEWA, 2018). Nevertheless, according to the Ninth Development Plan from 2010 to 2014, the municipal water demand is expected to grow at an annual growth rate of 2.1% (MEP, 2010). In 2016, average municipal water consumption was about 270 L/capita/day (MEWA, 2018; CDSI, 2016). However, other literature mentioned averages ranging from 260 to 300 L/capita/day (MEP, 2005; World Bank, 2005, 2010).

Estimating the future water demand for water system planning and design, water resources management, and water utilities asset management is important. Demand management policies and forecasts become more critical in regions with scarce water supplies, such as

Riyadh (Rahmanian et al. 2015 and Almutaz et al. 2012). With the importance of water demand forecasting, few literature, studies, and data are available in KSA that discuss and examine this topic (Almutaz et al., 2013). However, the existing literature is generally outdated.

The scientific studies documented different models for water demand forecasts, probabilistic or deterministic (Worthington & Hoffman 2007; Davis 2003 and Arbues et al. 2003). The driver for selecting a forecast model is the data quality and its level of certainty (Ouda et al. 2017). The model will be incredibly efficacious when the data are highly accurate and high-quality (Cheng & Chang 2011). Nevertheless, in cases where the critical explanatory or variables factors are unreliable, the validation of such determined models will be restricted (Khatri & Vairavamoorthy 2009). This applies to countries such as KSA, where the temperature is the single variable (Almutaz et al. 2012). Other possible variables are uncertainties, including population, housing growth rate, family income, immigration, water pricing policy, and the inefficient management of the unaccounted-for-water (UFW) (Almutaz et al. 2013).

During 2007 – 2013, municipal water production increased by 40% (from 5.76 MCM/day to 8.22 MCM/day) due to significant investments in desalination plants and groundwater (nonrenewable) extraction. During the same period, the KSA population increased by only 19% (from 25 to 29.8 million). Table 0 - 1 presents a simplistic water production projection based on the historical trend below. However, this is not considered in this study as a water demand forecast scenario; instead, it is a situation that should be corrected by implementing recommendations related to water conservation and water demand-side management.

Table 0 - 1 Water demand projection based on historical trends

Year	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Population[1] (Person)	25,006,539	25,831,333	26,683,332	27,563,432	28,299,735	29,055,835
Production[2] (m^3/d)	5,760,712	5,845,214	6,186,136	6,652,355	7,060,296	7,363,338
Allocation (L/capita/day)	230	226	232	241	249	253
Year	**2013**	**2020**	**2025**	**2030**	**2035**	**2040**
Population (Person)	29,832,265	34,512,313	37,174,177	39,640,554	42,223,825	44,922,884
Production (m^3/d)	8,219,184	10,139,178	12,034,932	13,930,685	15,826,438	17,722,192
Allocation (L/capita/day)	275	294	324	351	375	395

[1] Population for 2007-2012 is based on CDSI data.

[2] Production data for the period 2007-2012 provided by MoWE. Production data for 2013 extracted from IPS system (MOWE). Production data from 2014-2040 is based on projections for BAU scenario

The projections based on historical trends indicate that by 2040, the per capita allocation will increase to 395 L/capita/day, as shown in Figure 0- 1, with no guarantee that the water demand will be covered water supply level will be improved. A few cities experience frequent interruptions despite supplying 300 L/capita/day. It would be difficult and expensive to supply 395 L/capita/day; thus, cities requiring this amount would probably experience an unreliable and discontinuous supply.

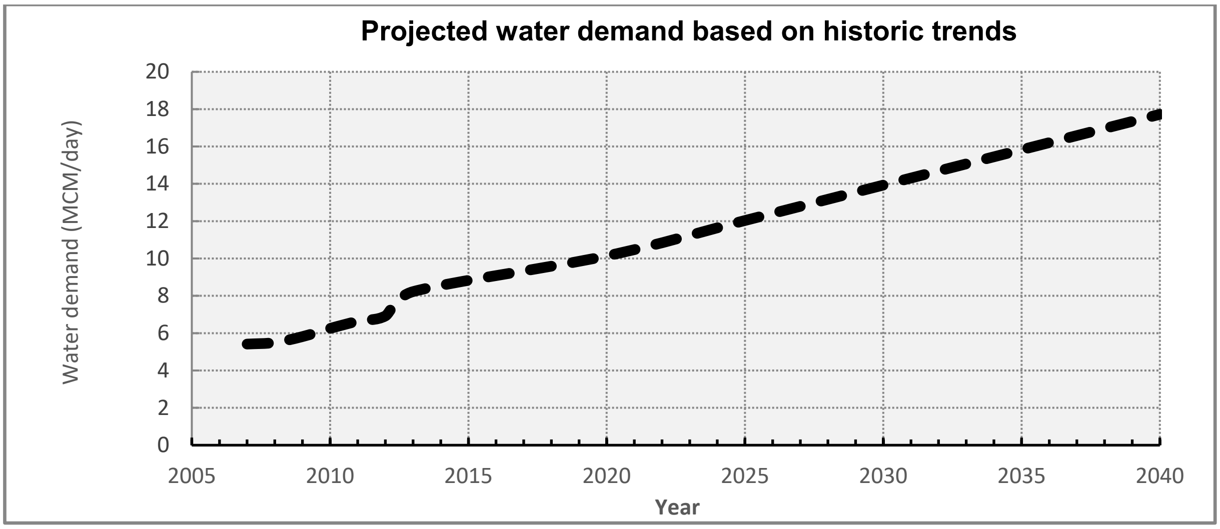

Figure 0- 1 Projected water demand based on historical trends

The approach to developing a demand forecast at the point of delivery to the customer was adopted to separate components as far as the data permits and to associate a fraction of the demand forecast to each component based on the best available information.

The existing water supply data reflect the water allocation from the public (NWC and MoWE) systems but do not include self-water supply (private tankers and wells). Therefore, it represents the gap between the water allocation from the public water supply systems and actual water demand. The data gaps have been filled by assuming the following, based on the existing studies and interviews with different stakeholders:

- Optimum residential water consumption demand[3] for a connected household: 100 lcd as recommended by WHO (2003).
- Leakage in water transmission and distribution: 33% (3% in transmission[4], 30% in distribution[5])

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[3] consumption = Production - Leakage (transmission + distribution)

[4] Water transmission efficiency assumed at 97%.

[5] According to NWC, water distribution efficiency in the major cities varies from 65% to 80%. No data is available for medium and small cities managed by regional directorates of MoWE.

- Residential water consumption: 80% of municipal water consumption[6].
- Non-residential[7] water consumption (government, small industries and commercial): 20% of municipal water consumption.

The water production data for 2016 were extracted from the MEWA annual report. The 2016 population is taken from the Central Department of Statistics and Information (CDSI) data. The estimated per capita water consumption for 2016 for the 13 regions of the KSA is presented in Table 0 - 2. The purpose of calculating per capita water consumption is to evaluate the regional factors that influence consumption. Water availability is the main factor affecting current and past municipal water consumption, irrespective of the margin of error and uncertainty in the 2016 water demand evaluation.

Table 0 - 2 KSA municipal water demand and per capita consumption for 2016

Region	2016 Population (Person)	2016 water consumption (MCM)	2016 Per capita water consumption (L/capita/day)
Riyadh	8002100	1,032	353
Makkah	8325304	707	233
Eastern Province	2080436	184	242
Al Qassim	1387996	123	243
Aseer	4780619	659	378
Jazan	2164172	101	128
Al Baha	890922	71	218
Najran	684619	56	224
Tabouk	359235	24	183
Al Madinah	1533680	61	109
Ha'el	569332	24	115
Al Jauf	466384	43	253
Northern Boarders	497509	44	242
Total KSA	**31742308**	**3,129**	**270**

The MoWE municipal water demand forecast developed in the national master plan for municipal water supply is based on supply-side management with a fixed per-capita approach. Per capita water allocation for each city is set according to the city size (Table 0 - 3). This approach assumes

[6] The available water supply data are not segregated by type of user (residential, government, industrial, commercial). According to international benchmarking, residential water consumption could represent 50 to 90% of total municipal water supply depending of the city size and existing economic activities (touristic, industrial, universities, administrative…).

[7] Main non residential water users are administrations, mosques, schools-universities, hotels, restaurants and military barracks. Industries are mainly located within specific industrial cities equipped with independent water supply system. Moreover, the majority of the municipalities are using reclaimed water or raw groundwater for landscaping and parks.

that supply controls the water demand, which is directly proportional to population growth, and that per capita allocation will not change in the future.

Table 0 - 3 MoWE criteria for water demand forecast

Category	Major cities	Moderate cities	Small Towns
Population (person)	Greater than 85,000	85,000 to 5,000	Less than 5,000
Per Capita (L/capita/day)	250	200	150

Per capita demand is based on political criteria of the MoWE, in which water allocation includes residential and non-residential water components and losses in distribution and is used as the design criteria for water production facilities.

The forecast based on MoWE criteria expects a per capita reduction of 14%. The water supply will likely increase by over 30% from 8.22 MCM/day in 2013 to 10.66 MCM/day in 2040 (Table 0 - 4).

Table 0 - 4 MoWE municipal water demand forecast

Year	2013	2020	2025	2030	2035	2040
Production (m^3/d)	8,218,437	8,256,608	8,783,719	9,383,836	10,007,558	10,664,952
Per capita (L/capita/day)	275	239	236	237	237	237

The National Water Strategy (NWS, 2013) aims to reduce per capita consumption from 275 to 170 L/capita/day (38% reduction). It will be achieved through water tariff reform, technology, and behavioural changes. It is all based on a belief that the general use of water-saving devices and appliances, combined with behavioural changes, will allow water consumption to fall to 170 L/capita/day without affecting the standard of living.

The water demand forecast based on the NWS target indicates that water demand could decrease from about 8.22 MCM/day in 2013 to approximately 7.64 MCM/day in 2040, as shown in Table 2-5 be too optimistic and may be difficult to achieve by 2040. The primary water conservation and water demand tools would need more time and efficient political willpower to reform water tariffs and agricultural water use and improve public awareness. A comparison of projections based on NWS, MoWE (Allocation), and historical trend forecasts is presented in Figure 0- 2.

Table 0 - 5 Municipal water demand forecast according to NWS-2013

Year	2013	2020	2025	2030	2035	2040
Population (person)	29,832,265	34,512,313	37,174,177	39,640,554	42,223,825	44,922,884

Production (m^3/d)	8,218,437	8,567,172	8,502,033	8,290,176	8,004,167	7,636,890
Per capita (L/capita/day)	275	248	229	209	190	170

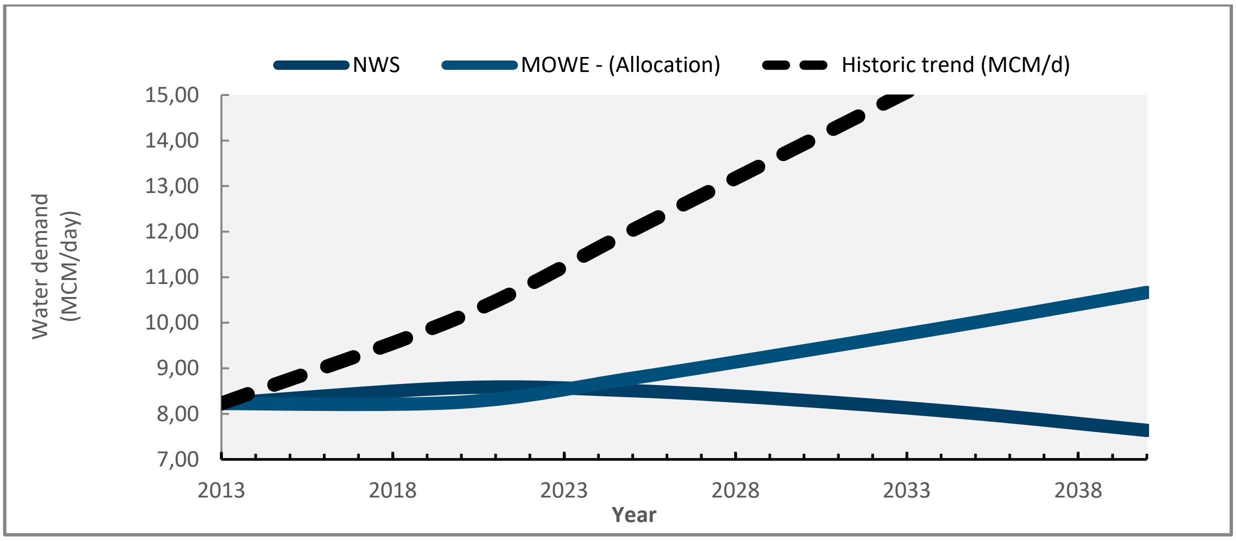

Figure 0- 2 Municipal water demand forecast – MoWE and NWS Projections

The existing data (MoWE, NWC, etc.) about municipal water supply are limited to water production on a governorate basis (117 governorates) in 13 regions. Water consumption is partially metered in the major cities (Riyadh, Jeddah, etc.), while leakage and water consumption for different consumers (domestic, industrial, commercial, government) are roughly estimated. The current water supply statistics cannot be considered a water demand trend; several regions with limited water resources, such as Al Baha, Hail, and Najran, have poor water supply coverage. Those regions rely on self-supply from private wells and tankers to meet their water demand. On the contrary, a few regions, such as Al Qassim and Eastern Region, are beneficiaries of generous water supply leading to overconsumption, which indicates a water wastage attributable mainly to low tariffs (0.15 SR/m3 for the first 50 m3/month) and lack of awareness among consumers to conserve water.

Population growth, industrialization, and development have pressured KSA water sources and infrastructure. Moreover, the absence of appropriate data to develop detailed mathematical models (correlation, extrapolation, etc.) is a fact. Consequently, there is an instant need to raise the water capacity to match the projected demand and preserve its security and reliability. It is then necessary to find methods and solutions that increase the KSA’s water system's efficiency. A critical factor in this effort is to realize and classify how water is consumed within its micro-components and segment.

OBJECTIVES of THE THESIS

All developments in this thesis are oriented towards two main objectives:

Main objective 1
To carry out a comprehensive analysis of the water management situation in KSA. This will be done by reviewing the availability of the natural resource, the stakeholders involved, population and rates of resource use. Aspects related to security of supply and management, water and environmental quality and the impact of climate change will also be considered.

Main objective 2
To develop a consumption model for urban water use in KSA.

This main objective is subdivided into 3 secondary objectives:

- Bibliographic review that portraits the current state of the art in terms of knowledge of urban water use, with special attention to the different sectors that make it up.

- Elaboration of a mathematical model to represent the current water consumption nowadays, and to project water consumption in the future. This model should consider the parameterisation of the factors that intervene in the process of water use, taking into account their different natures.

- Application of the developed model to various case studies in KSA. These case studies will serve, on the one hand, to carry out some fine tuning of the parameterisation developed in the model and, on the other hand, to show its applicability to the context that gives meaning to this thesis: KSA.

STRUCTURE of THE THESIS

A brief description of each chapter in this thesis follows below.

Chapter One

The overview refers to numerous studies and reports produced internationally and in the Kingdom of Saudi Arabia (KSA). It starts with an overview of the water sector to understand the current water situation, existing water resources and current water management practices with its stakeholders. After that, it evaluates urban areas' water supply and consumption to develop a water budget.

Chapter Two

It includes an assessment of water quality and security of supply by looking at water resource diversity, storage and water treatment reliability and transmission redundancy by considering environmental and social impacts. Then, it sets out current Integrated Water Resources Management (IWRM) practices. After that, it defines and describes sustainability and the process towards achieving an enduring regime with the accompanying transitional and resourcing requirements. Finally, the conclusion and recommendations for further implementation are detailed.

Chapter Three

The municipal water consumption will be developed by estimating water consumption for different types and categories of water users in an urban environment. The main assumptions made during the development of the model have been the following:

- Municipal water users have been classified into two main sectors, residential and non-residential. Each one of them has been further subdivided into different categories.
- A water consumption model for each water-use category has been defined, and benchmarks from previous studies in the scientific literature have been set.

In this area, a lot of effort has been put into developing a consumption model for municipal water by residential and non-residential users, including hotels, restaurants, cafes, offices, schools, universities, hospitals and mosques.

The already developed model considers these various types of water uses (categories) within each sector to obtain the total consumption.

Chapter Four

A model is developed by describing residential and non-residential water consumption. Water consumption is modelled through a function of the main drivers.
A detailed model that describes how much water a residential user consumes at their home with several consumption drivers. Moreover, as individual water end-use discrimination is not viable for non-residential users, the consumption model developed has been simplified by considering the specific drivers for each consumption category that best describes the water uses.

Chapter Five

The development of the municipal water consumption model in EXCEL has been completed, incorporating the new information gathered about the water consumption of residential and non-residential users

A great effort has been put into producing a significant amount of work to be done concerning incorporating the individual drivers of each type of residential and non-residential user. These drivers need to be such that they can be found for the total KSA.

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ABBREVIATION

KSA	Kingdom of Saudi Arabia
MoWE	Ministry of Water and Electricity
SWCC	Saline Water Conversion Corporation
NWC	National Water Company
ECRA	Electricity & Co-Generation Regulation Authority
MOA	Ministry of Agriculture
GAIA	General Administration of Irrigation Affairs
ADF	Agriculture Development Fund
KAUST	King Abdullah University of Science and Technology
IISD	International Institute for Sustainable Development
IWPPs	Independent Water and Power Projects
ADB	Asian Development Bank
AWDO	Asian Water Development Outlook
GCMs	General Circulation Models
STP	Sewage Treatment Plants
KPIs	Key Performance Indicators
FF	Fouling Factor
MSF	Multi-Stage Flash
MED	Multi-Effect Desalination
RO	Reverse Osmosis
PA	Polyamide
$-USD	United States, Dollar
SR	Saudi Riyal
CAPEX	Capital cost
OPEX	Operation and maintenance costs
GDP	gross domestic product
KWh	Kilowatt-hour
mBq	mega becquerel
mg	Milligrams
kg	kilogram
BCM	billion cubic meters
MCM	Million cubic meters
km^2	Square kilometre
Mm^3	Million Cubic Meters
m^3	Cubic Meters
L	Litres
m	meter, or metre
cm^2	Square Centimeter
km^2	Kilometer Square
km	Kilometre
mm	Millimetre
mg	Milligram
^oC	degree Celsius
ppt	parts per trillion
Min.	Minute
CDSI	Central Department of Statistics and Information
TFR	Total Fertility Rate
UN	United Nations
USAID	United States Agency for International Development
WSAA	Water Services Association of Australia
UFW	Unaccounted for Water
STATS	Population and Housing Census from the General Authority for Statistics

Chapter 1
OVERVIEW OF THE WATER SECTOR IN KSA

1 OVERVIEW OF THE WATER SECTOR IN KSA

1.1 Introduction

The Kingdom of Saudi Arabia (KSA) has seen tremendous changes in its social and economic spheres in the last 30 years. Wealth from oil revenues has made it possible for the government to develop all sectors of the economy. The massive agricultural sector growth at an unprecedented rate during this period resulted in massive withdrawals from the country's limited deep groundwater reserves. The development of cities and the rise in living standards has caused domestic and industrial water consumption to increase many folds.

The constant pressure on the country’s water resources has made it necessary to develop both conventional and unconventional water resources (surface and groundwater) (desalination of seawater and treated wastewater). More than 230 dams have been constructed to utilize surface water available only in some regions of the country. The Kingdom's huge non-renewable aquifers were also extensively studied and utilized for different uses. Many desalination plants were built on the Red Sea and the Arabian Gulf Coast, producing water for coastal urban centres and many cities in the country's interior, including Riyadh's capital city. KSA is currently the world's largest producer of desalinized seawater. Wastewater treatment plants were also constructed in many urban areas; however, the utilization of treated wastewater is still limited.

Despite the tremendous efforts made by the Saudi government to develop the water supply in the country, water consumption in KSA has reached alarming levels. The service level is still ranked poor regarding water distribution continuity (24/7) and water conservation (reuse, recycling, leakage prevention etc.).

According to the Ministry of Water and Electricity (MoWE) annual report, between 2008 and 2018, there has been a steady increase in water consumption in the last few years, and the country’s total water use has increased from approximately 17.8 billion cubic meters (BCM) in 2008 to 25.99 BCM in 2018. During the same period, the agriculture water demand increased from around 15 BCM in 2008 to 21.2 BCM in 2018. In 2018, the agricultural sector consumed the lion's share by using approximately 82% of the total water supplied despite widespread recognition and advice that agricultural water use at the current scale is not sustainable.

The water demand for 2012 was mainly satisfied by non-renewable groundwater, which accounts for approximately 74% (15.45 BCM) of the total supply from various sources. In addition, renewable water resources and desalinated water contribute around 17.5% (3.70 BCM) and 7.4% (1.54 BCM), respectively, and the contribution from wastewater is minimal (approximately 1.1%) (MoWE, 2013).
Many industrial and agricultural centres on the Shelf aquifer use excessive and non-sustainable quantities, leading to severely declining groundwater levels and deteriorating water quality (FAO, 2009). There is evidence of localized groundwater pollution in areas with

extensive agricultural activity, which includes high nitrate levels in some agrarian wells. Thus, good-quality water from the aquifer is mixed with poor-quality water from the overlying formations (FAO, 2009).

1.2 Available Water Resources

The availability of water resources is highly variable throughout KSA. The different areas for the availability and utilization of water resources include the Red Sea Coast, the Arabian Shield, the Shelf and the East Coast, as shown in Figure 1- 1. Both the coastal areas rely heavily on desalinated water, with some utilization of renewable water resources on the Red Sea Coast and non-renewable groundwater on the East Coast. Renewable water resources are the only water supply sources in the Arabian Shield area due to relatively higher annual rainfall (500 mm/year in the southern portion) than the rest of KSA (MOEP, 2010c). It has been established that the south Shield is the only area in KSA where sustainable use of water resources is possible. On the Shelf, non-renewable groundwater is the only water source with some remote desalinated water supply from the East Coast (MOEP, 2010a and MOEP, 2010b).

Figure 1- 1 Areas of KSA concerning water resources availability (MOEP 2010a)

The contribution of different water sources to consumption in KSA over six years (MoWE 2007-2012) is shown in Figure 1- 2.

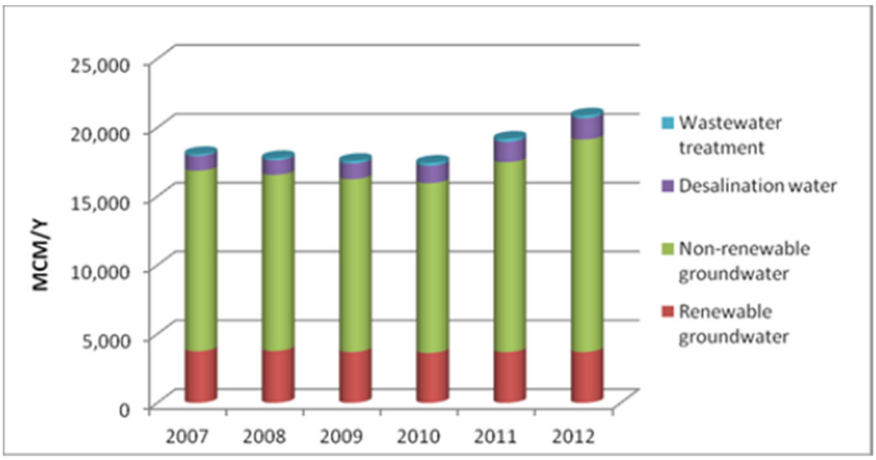


Figure 1- 2 Contribution of different water sources to KSA supply (MCM/year)

1.3 Stakeholders and Water Management in KSA

1.3.1 Stakeholders

MoWE is responsible for policy and regulation of water services and all water matters, including drainage, sewage and reclaimed water (FAO, 2009). The Water Act enables MoWE to manage water resources across KSA (FAO, 2009). More specifically, MoWE is responsible for the following:

- Ownership of water resources and infrastructure.
- Protection and sustainability of water resources.
- Water sector management.
- Regulation and licenses on water use.
- Regulation and licenses of water services.
- Quality and pollution control.
- Settlement of water conflicts.
- Development of water legislation and monitoring.
- Breaches and sanctions.
- Transitions and final provisions.

MoWE shares the KSA water delivery sector with other state organizations, notably the Saline Water Conversion Corporation (SWCC), National Water Company (NWC) and the Electricity & Co-Generation Regulation Authority (ECRA). MoWE is organized into 13 regional directorates, similar to administrative regions. Although MoWE deals with the water resources aspects of irrigation, the Ministry of Agriculture (MOA), in 2005, created the General Administration of Irrigation Affairs (GAIA) to organise, plan, monitor, develop, operate, and maintain irrigation and drainage projects.

Key governmental agencies involved with water resources management in KSA include the Ministry of Agriculture, Ministry of Municipal and Rural Affairs (MoMRA), General Authority for Meteorology and Environment, Ministry of Finance and Industry and several Research Institutions.

Since 2003, MoWE has been responsible for policy and regulation of water and sanitation services (FAO, 2009) until 2016, when the Royal Decree was released to merge MoWE with the Ministry of Agriculture (MEWA 2016). The recently established Electricity and Co-generation Regulatory Authority (ECRA) only regulates privately owned desalination plants (Al-Saud, 2010).

1.3.2 Service provision

The private and public sectors share the responsibility for service provision. Since 2013, the National Water Company (NWC) has been responsible for the water supply and sanitation in Riyadh, Jeddah, Makkah and Taif in partnership with foreign private operators (NWC, 2013). In other cities, water supply and sanitation are still under the responsibility of MoWE through its regional directorates and branches (MoWE, 2013). The local governments have no role in service provision in Saudi Arabia.

Desalination plants are controlled and operated by the Saline Water Conversion Corporation (SWCC) or by private companies called Independent Water and Power Projects (IWPPs), which sell water and energy to a public entity called the Water and Energy Company (SWCC, 2013). Private companies run many wastewater treatment plants under BOT contracts.

Comprehensive regulations are now in force to manage water resources, with responsibilities assigned to several institutions. Despite this progress, enforcing these regulations remains challenging for the KSA government.

1.3.3 Tariffs

Average water tariffs range from 0.10 SR/m^3 (US$0.03/$m^3$) to 6 SR/$m^3$ (US$1.8/$m^3$) (Ouda, 2013 and MoWE, 2013) and, which are among the lowest in the world and are not reflective of the cost of supply. KSA has an increasing block tariff structure, but most consumers fall in the first block where water charges are minimal. Customers with a water use of less than 50 cubic meters per month pay only 0.10 SR/m^3. In other countries where increasing-block tariffs are used - such as in Jordan, Yemen or Morocco - the lifeline consumption benefiting from a lower tariff level is typically set at 20 cubic meters per month or less. The tariff level, structure, and low share of metering provide little or no incentive to conserve water.

One cubic meter of water supplied by a water tanker may cost as much as 10 Riyals (US$ 2.7) (MoWE, 2013), or about 100 times more than water supplied through the network. Citizens not connected to the piped network pay 100 times more for water than connected households.

1.4 Water Resources

1.4.1 Seawater desalination

KSA has been producing desalinated seawater for over 40 years, being the world's largest producer of desalinated water. Around 60% of the domestic water needs of the country are currently being met by desalinated water. Still, the production is expected to grow in future. KSA is planning huge investments in its water desalination capacity to keep pace with growing water demand. However, despite massive investments, the demand is growing at a rate that threatens to outstrip supply. Therefore, long-term planning is necessary to optimize the integrated management of water resources that would ensure judicious use of investment while maintaining the security of the water supply.
In 2015, the desalination capacity in KSA was around 6.91 (MCM/day). The installed desalination capacity was almost equally distributed between the Red Sea Coast, with 3.61 (MCM/day) and the Arabian Gulf Coast, with 3.3 (MCM/day). The number of plants on the Red Sea coast was sixteen as opposed to five on the Arabian Gulf Coast (SWCC, 2015), as shown in **¡Error! No se encuentra el origen de la referencia.**. With the current installed capacity, the KSA's desalination plants can contribute approximately 2.52 BCM annually to the water stream.

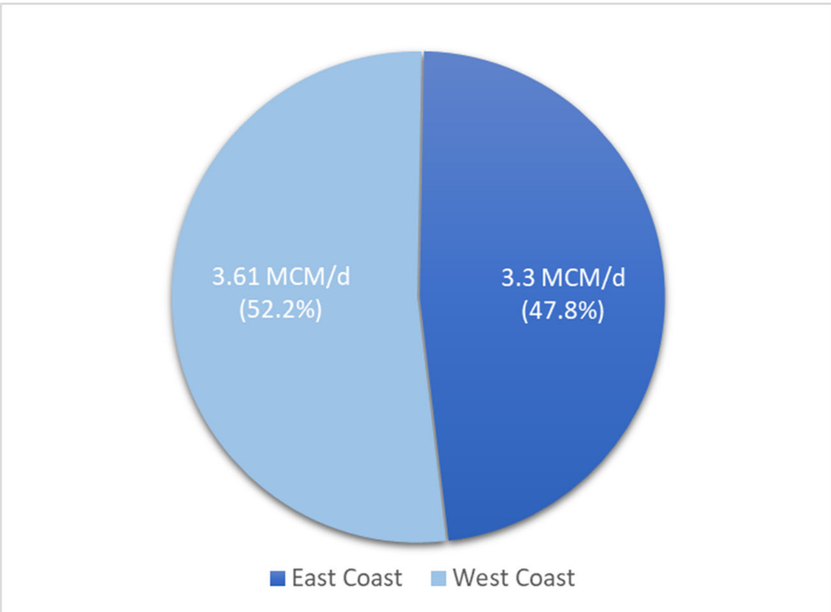


Figure 1- 3. Desalination capacity (MCM/day) on the east and west coast (2014-2015)

A large proportion (16 out of 21) of the major desalination plants are located on the Red Sea coast and deliver water to the cities of Jeddah, Makkah, Madinah, Taif, Abha, Khamis Mushait and several smaller coastal towns and villages. The plants on the Arabian Gulf coast supply the population centres on the coast as well as Riyadh and Buraidah (Al Qasim). Based on a planned operational life of 35 years, some of these plants would need to be decommissioned in the near future and thus warrant an alternative (SWCC 2015). The location of the major desalination plants on both coasts is shown in Figure 1- 4.

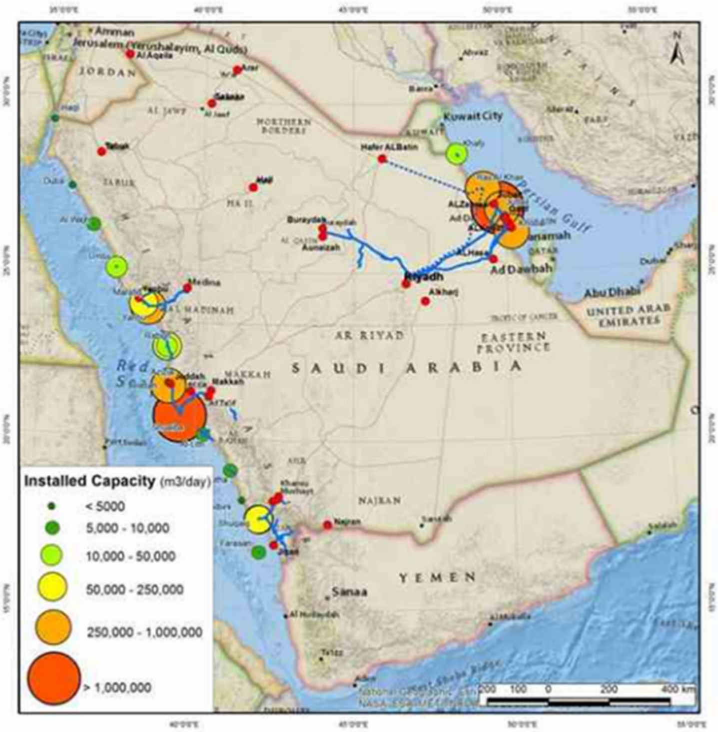


Figure 1- 4 Desalination plant location map (SWCC 2015)

The cost for desalinated water supply varies considerably depending on the scale, technology type, infrastructure requirements and supply location offset concerning the supplying plant. KSA uses a tremendous amount of energy to provide power to the country's government-operated water desalination plants.

1.4.1.1 Desalination technologies - advantages and constraints

In 2012, the bulk of desalinated water production was based on the thermal Multi-Stage Flash (MSF) process accounting for approximately 70% of the total water production. The remaining 30% is almost equally shared between Multi-Effect Desalination (MED) (about 16%) and membrane-based (mostly Reverse Osmosis - RO about 14%) plants (SWCC, 2012).

Table 1- 1 presents the total water production in 2011-2012 by KSA's three main types of desalination plants.

Table 1- 1 Desalination production (2011-2012)

Technology	Average Production (m^3/day) – East Coast	Average Production (m^3/day) – West Coast	Total Production (m^3/day)
MSF	1,425,216	2,349,048	3,774,264
	-64.40%	-74.40%	(70.2 % of Total)
MED	751,143	97,367	848,510
	-34.00%	-3.10%	(15.8 % of Total)
RO	36,368	713,180	749,548
	-1.60%	-22.50%	(14.0% of Total)
Total	2,212,727	3,159,595	5,372,321

The selection of desalination technology and the plant capacity depends on the specific conditions that apply to the individual project. The following factors can explain previous development and trends in the choice of desalination technologies in KSA:

a. The primary energy costs in KSA are very low. Hence, the comparatively high energy demand for thermal desalination technologies is of secondary importance.
b. The rapid increase in population and wealth in the 1970s ("oil boom") caused a rapid increase in water and power demand. At the time, the MSF technology was a perfect fit for two reasons: First, it was the only technology with a proven track record for large-scale production. Second, combining a power plant with a thermal desalination plant in a dual-purpose configuration is advantageous for both utilities as the MSF plant takes care of the condensation of steam, which has been generated in the power plant and has to be condensed anyway.
c. During the later years, the MED can be considered a competing technology to MSF in high-capacity desalination plants, achieved by increasing the unit capacities from some 4,000 (m^3/day) (Al Azizia island) in the late 1980s to 800 000 (m^3/day) (Marafiq).
d. In the last decades, Seawater Reverse Osmosis (SWRO) technology did not succeed in the Arabian Gulf region because major plants fell short of achieving their design capacities.

According to recently planned plants (Ras Al Khair, Yanbu 3 and Rabigh), the trends expected for the next few years continue the past development. No major change in desalination technology development will likely occur in the short and medium term. The experience of different desalination technologies gained during the last decades allows an objective assessment of advantages and constraints.

SWCC database of existing desalination plants, including the plants, owned and operated by IWPPs. Available operational statistics from 2008 to 2012 have made it possible to extract different KPIs related to water production, energy consumption (KWh/m^3), regional analysis (Arabian Gulf versus Red Sea), different technologies and providers and the retirement profile. However, this national benchmarking and comparison between different technologies and plants are still theoretical and simplistic because of the fast technology improvements and evolution during the last few decades.

MSF processes were introduced in the early 1950s. Both MSF were the two desalination plants (Duba and Alwajh) installed and commissioned in KSA in 1969. Thermal processes, especially MSF, have been the process of choice in KSA. The last 15 years have seen efforts in KSA to build more MSF desalination plants, with a small opportunity for MED.

Until 1982, extraction condensing turbines were used in the dual-purpose power plant associated with distillation (MSF). From 1983 onwards, those turbines were replaced by back-pressure turbines, which were more efficient for this system, giving a lower power-to-water ratio and higher thermal efficiencies. However, due to limited knowledge of the chemical products, those designs were very conservative, using a very high Fouling Factor (FF), nevertheless yielded positive results in the long-term with the use of a new antiscalant and the ball cleaning system. Although a high FF in the design meant oversizing the heat transfer surface and was thus more expensive, it proved successful using new chemicals and cleaning methods. This allowed the operation at top brine temperature equal to or even higher than maximum design values, with an increase in water production. The high capital cost (CAPEX) and operation and maintenance costs (OPEX) associated with MSF plants have been, to some extent, mitigated by applying the principal of the "economy of scale" by building desalination plants with high installed production capacity. The evolution of the scale of the MSF units is evident from the following:

e. 1999-2001: Yanbu II, Khobar II: 12,500 m^3/day/unit.
f. 2002 Shouaiba II: 45,600 m^3/day/unit.
g. 2013: Ras Al Khair: 91,200 m^3/day/ unit.

The first membrane-based seawater desalination plant was installed in Jeddah in 1979 using spiral wound membranes with modest results. However, corrosion and other operational problems delayed the installation of new RO seawater plants in KSA for some years. In 1993, the first large-scale plants (Jeddah I and Medina-Yanbu I) were installed on the Red Sea Coast. These plants were based on hollow fibre membranes (Toyobo) made of cellulose acetate (as opposed to polyamide (PA) hollow fibre membranes used at the time), which permitted disinfection treatment with chlorine. Those membranes were later used in all the RO desalination plants installed on the Red Sea Coast.

On the Arabian Gulf coast (Al Jubail), the first membrane-based desalination plant with a capacity of 90,000 m^3/day, fitted with polyamide (PA) hollow fibre membranes (Dupont), started operation in 1997. With no power recovery devices, this plant had a specific power consumption of around 7 kWh/m^3. Improvements in RO technology have helped reduce energy consumption from around 8.5 kWh/m^3 in 1980 to around 2.4 kWh/m^3 in 2009. These improvements include:

h. membranes: Higher flow, lower feed pressure, higher rejection.
i. pumps: Larger and High-pressure pumps with higher efficiency (larger RO racks).
j. recovery devices: use of recovery turbines.
k. improvement of the design and equipment: pressure exchangers.
l. improvement of high-tech control systems.

Table 1- 2 shows average energy requirement for the different desalination processes mentioned above

Table 1- 2 Energy requirements for different desalination processes

Technology	Electrical Energy (kWh/m^3)	Thermal Energy (kWh/m^3)	Equivalent Thermal Energy (kWh/m^3)	Total Energy (kWh/m^3)
Seawater Reverse Osmosis (SWRO)	3 0 - 5.5	0	0	3.0 – 5.5
Multi-Effect Distillation (MED)	1.5 – 2.5	60 - 110	5.0 - 8.5	6.5 – 11.0
Multi-Stage Flash (MSF)	4.0 – 6.0	50 - 110	9.5 – 19.5	13.5 - 25.5

Source: Wangnick Consulting (2010) and DESWARE – Encyclopedia of desalination and water resources.

1.4.2 Non-renewable groundwater

The non-renewable groundwater in KSA is stored in more than 20-layered principal and secondary aquifers of different geological ages, forming the bulk of the available water resources. The principal aquifers, characterized by relatively shallow depths, good water quality, wide spatial extent, greater thickness and relatively high permeability, have been the primary water source in KSA (FAO, 2009).

The Arabian Shelf includes the deep sedimentary aquifers (mostly limestone and sandstone) that overlay the basement rock formation known as the Arabian Shield and covers about two-thirds of KSA or 1.485 million km^2 or a little over two thirds of KSA (MAW, 1984). Most aquifers store fossil water and are classified as non-renewable due to the absence of or negligible recharge (FAO, 2009). Only the alluvial aquifers and those in the Basalt layers are recharged by surface water and considered renewable groundwater resources (Ouda, 2014).

The total exploitable non-renewable groundwater resource combined from the Principal and Secondary aquifers was estimated at 2360 BCM (MOEP, 2010c) in 2008.

1.4.2.1 General hydrogeology of KSA

The hydrogeology of KSA can be subdivided into two major geological and physiographic units. In the western Arabian Shield (Crystalline Najd), crystalline rock is present at or near the land surface. A thick sedimentary rock deposit underlies the Sedimentary Najd and Eastern Province (Sedimentary Sequence). The sedimentary rock strata dip to the east so that progressively younger rocks are encountered at the land surface from the centre of KSA to the Arabian Gulf coast. Due to their geology, the eastern and western parts of the Kingdom have distinctly different hydrogeological conditions. The sedimentary strata underlying the east half of KSA contain multiple aquifers, separated by less permeable confining or semi-confining strata. The Arabian Shield's crystalline rock, except for shallow fractured and weathered zones, is essentially impermeable and forms the base of the local groundwater system. The only significant aquifers are shallow, coarse-grained alluvial sediments deposited in wadi channels and some aquifer systems within basalt Harrats. The Wadis along the western coast originate in the eastern Highlands and extend in a generally westward direction to the Red Sea (KAUST, 2011).

Recharge rates in both the eastern and western parts of KSA are low, with the overall average rate being less than 5 mm per year. The mountainous areas of the west part of the Arabian Shield have significantly greater than average rainfall and recharge and thus have greater renewable groundwater resources in the wadi aquifers. However, wadi aquifers have low storage volumes and are vulnerable to rapid depletion. The eastern part of KSA aquifers have very large storage volumes but are also vulnerable to depletion because of very low recharge rates. Water levels in these fossil aquifers are declining due to extensive agricultural withdrawals and, to a lesser extent, withdrawals for municipal potable supply (KAUST, 2011). The non-renewable groundwater in KSA, which exists in large parts of KSA (mostly Shelf) within the principal and secondary aquifers, forms the bulk of the available water resources.

1.4.2.2 Principal aquifers

The principal aquifers include Saq, Wajid (Lower and upper), Dhurma-Minjur, Tawil-Sharawra, Wasia-Biyadh, Umm Er Radhuma Dammam, and Neogene. These principal aquifers, characterized by relatively shallow depths, good water quality, wide spatial extent, greater thickness and relatively high permeability, have been the primary water source in KSA (MOEP, 2010a). Despite the huge storage potential of the principal aquifers, the overexploitation of these aquifers has deteriorated water quality and levels. In 2010, a planning and assessment study completed by the Ministry of Economy and Planning (MOEP, 2010a), the exploitable limits of Principal aquifers were determined by constraining the drilling depth to 2,000 m, the pumping height to 300 m below ground level and groundwater salinity to 2,000 mg/L. Based on these criteria, the exploitable potential of the principal aquifers was estimated at 2,360 BCM according to the limits of exploitability mentioned above (MOEP, 2010c). The detail of the estimated exploitable volume for all the principal aquifers is illustrated in Figure 1- 5. It is noted that this estimate did not include the exploitable groundwater volume for the Jubah-Jauf Aquifer, the Jilh Aquifer and the Middle Jurassic to Lower Cretaceous Aquifer. These aquifers are believed to hold approximately 2110 BCM of exploitable non-renewable groundwater.

A detailed discussion on each of the principal aquifers concerning hydrogeological aspects can be found in MOEP (2010c).

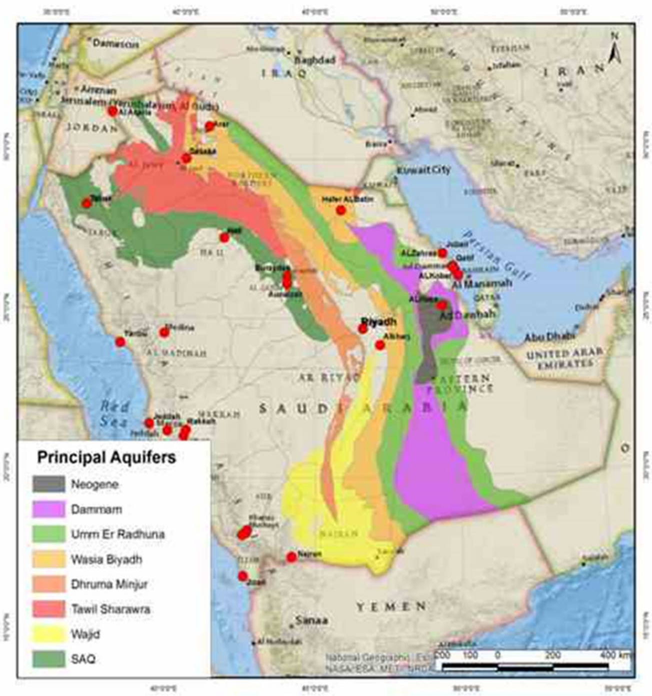


Figure 1- 5 Map showing the exploitable areas of the principal aquifers of KSA

1.4.2.3 Historical groundwater abstraction

The estimates of historical groundwater abstractions indicate that by 2008, 373 BCM of non-renewable groundwater had been abstracted for agricultural use (MOEP, 2010c). At the same time, the estimated cumulative abstraction of non-renewable groundwater for municipal and industrial use stands at approximately 41 BCM. The cumulative abstraction for the agricultural, municipal and industrial supply for 1975-2008 (MOEP, 2010c) is presented in Figure 1- 6.

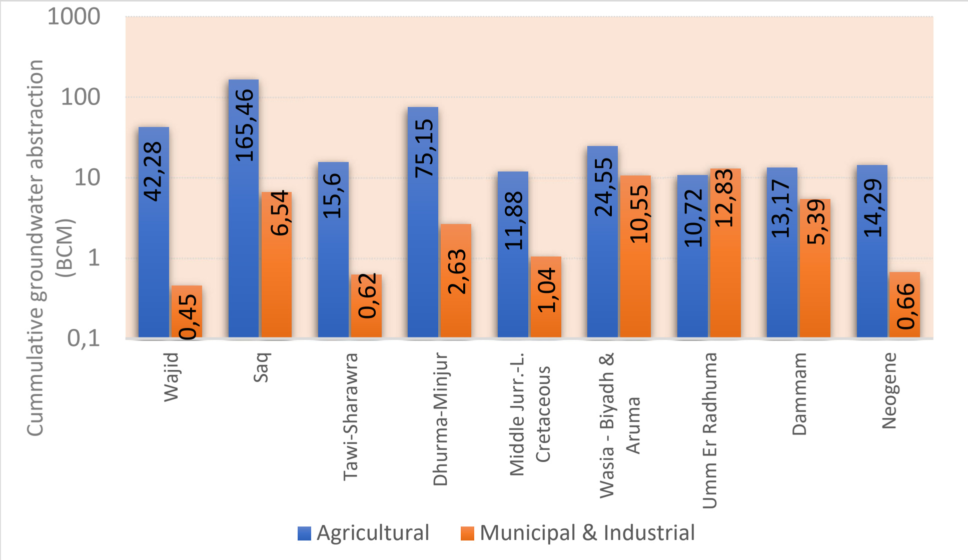


Figure 1- 6 Cumulative groundwater abstraction for agricultural and municipal/industrial supply 1975-2008

The 2008 estimates also indicate annual non-renewable groundwater abstraction of 13.45 BCM for agriculture and 1.3 BCM for municipal and industrial water supply. These abstraction estimates are based on a 3-year average (2006-2008) for which the estimates are available. If it is assumed that there has been no significant change in the groundwater abstraction rates over the last five years, approximately another 74 BCM has been consumed since the previous estimate became available in 2008. On a per aquifer basis, the average yearly groundwater abstraction estimates for agricultural, municipal, and industrial use are presented in Figure 1-7. The exploitable non-renewable groundwater volume is estimated at approximately 2286 BCM.

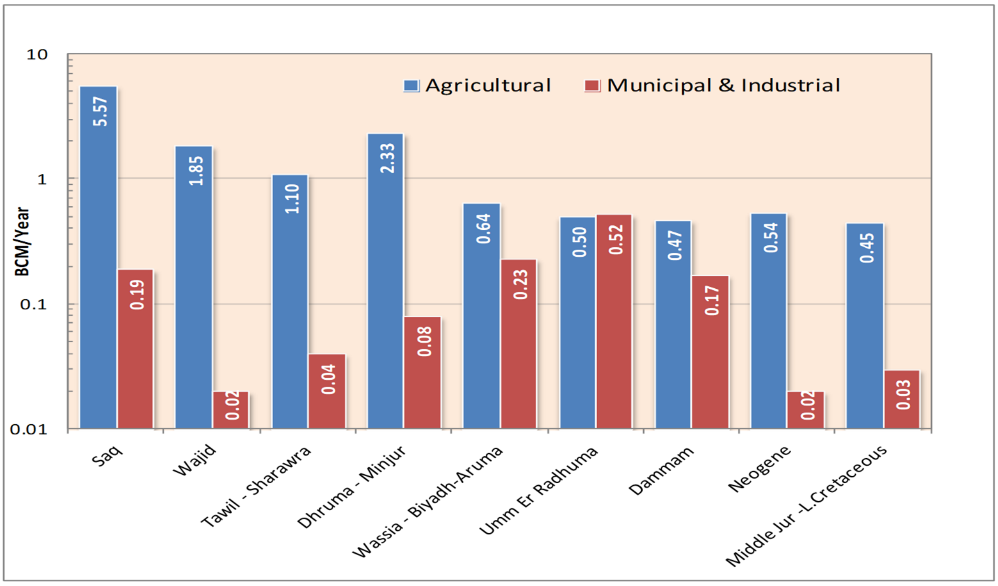


Figure 1- 7 Average annual groundwater abstraction between 2006-2008

1.4.2.4 Impacts of overexploitation on groundwater quantity

Overexploitation of the non-renewable groundwater resources has caused tremendous pressure on the long-term availability and viability of these resources in KSA, especially in areas that rely totally on non-renewable groundwater for industrial and traditional agriculture. A study (MOEP, 2010c) on the Shelf (Wadi Ad Dawasir, Al Hassa Oasis and Al Ajfar) focusing on these agricultural centres highlighted the extent of damage to groundwater quantity and, resultantly, the quality. A summary of each is provided in the succeeding paragraphs.

Wadi Dawasir, one of the major agricultural centres in KSA located about 600 km south of Riyadh, is responsible for 10% of the Kingdom's agricultural abstraction (approximately 2,000 MCM/year). The groundwater is almost entirely withdrawn from the Wajid Aquifer. Large-scale agriculture abstractions have caused a cone of depression 200 m deep and 100 km in diameter. Thus, the aquifer is practically unusable in the affected area, resulting in the elimination of traditional agriculture, damage to the natural environment, perishing of the natural vegetation and associated fauna and onset of erosion and desertification. It has been anticipated that the continuation of agricultural abstraction at the current rates would result in a total depletion of the Wajid Aquifer in 10 years around the centre of abstraction.

Al Hassa Oasis, located 300 km east of Riyadh, in the centre of the eastern province, uses an estimated 712 MCM/year of groundwater, 356 MCM/year for agriculture, 271 MCM/year for industrial use (oil industry) and 85 MCM/year for domestic supply) from Neogene, Dammam and Umm Er Radhuma Aquifers. Over-exploitation has increased measured drawdown from 70 m to 150 m and the extension of the cone of depression from 60 – 100 km. If the abstraction continues at the current rates, it is anticipated to dry more wells in the Dammam and Neogene Aquifers. The cone of depression will extend further, and groundwater quality will deteriorate.

Al Ajfar, located 120 km east of Hail and 500 km northwest of Riyadh, represents a large part of an industrial, agricultural area developed after the late seventies extending from Buraydha northwards towards Hail. The groundwater extraction (approximately 1193 MCM/year) is from the Saq aquifer, which has experienced a drawdown of roughly 150 (m) at the centre of the cone of depression. Draw-down values of 10 m/year are common in the area.

1.4.2.5 Water supply from groundwater

Based on the 2013 data from MoWE, there are 34 existing groundwater water treatment plants in KSA with a total treatment capacity of 1.058 MCM/day. Of the 34 plants in KSA, 14 are in the Riyadh region, while another five are in the east region, as shown in Figure 1- 8. These two regions combined account for approximately 90% of KSA's total groundwater treatment capacity. It is noted that the treatment capacity in a region does not imply that all municipal water being treated in one region is being utilized in the same region. In 2017, the total groundwater water treatment plants were 295, with a total production capacity of 2.068 MCM/day (MEWA, 2017).

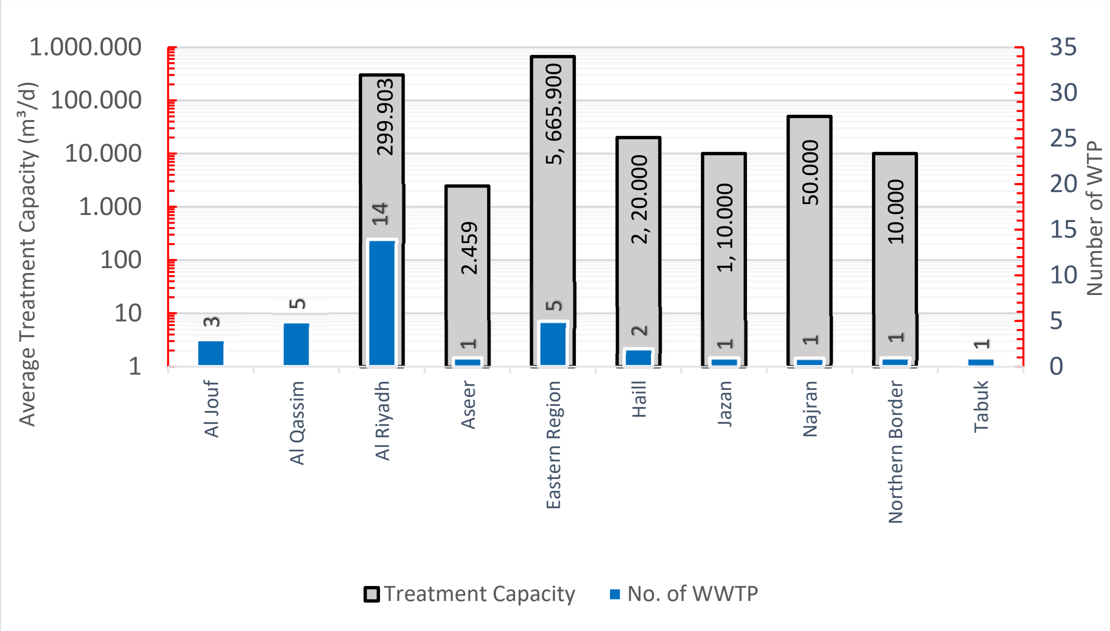


Figure 1- 8 Groundwater treatment capacity by region in 2013

1.4.2.6 Groundwater treatment process and transmission

The groundwater treatment process for drinkable water supply varies from simple chlorination to reverse osmosis. Common groundwater treatment plants to treat groundwater with high iron concentrations are typically designed with pre-treatment steps, including a softener system and sand filters followed by micro or ultra-filtration and RO membranes and chlorination for disinfection.

The MoWE has installed several small standalone RO Units with 300 m^3/day capacity to supply small rural villages. Large water supply systems such as Riyadh are mostly equipped with a full treatment process train: aeration, filtration, RO and disinfection.

Most groundwater transmission systems are limited to a few kilometres (less than 10 km). However, for Riyadh and Dammam, some good fields and groundwater treatment plants are located more than 100 km away (Al Hunain, Al Wasiya). They are blended with desalinated water before distribution.

1.4.3 Renewable water

Renewable water resources comprise surface and renewable groundwater stored in shallow alluvial aquifers and basalt layers of varying thicknesses and widths. These aquifers are mainly present in the southwest of the KSA. These aquifers have a storage potential of approximately 84 BCM (Zaharani et al., 2011; Abdurrahman, 2006). They are recharged from surface water runoff, mainly in the west, with some far south along the western coast (FAO, 2009).

Most of the renewable water resources of KSA occur in the western part of the country (i.e., the Arabian Shield and the Red Sea Coast). Renewable water resources depend on scarce and variable rainfall and are contained in alluvial deposits along the Wadi (ephemeral rivers/streams) beds. KSA does not have any permanent surface water resources. Flash floods

(Wadis) occasionally run for a short duration, depending on temporal and spatial variations in rainfall patterns. Ephemeral runoff and dam storage are the main contributors to surface water resources. KSA's total renewable water resources (i.e., surface water and groundwater) are estimated at 2,400 MCM/year (FAO, 2009 and MOEP, 2010b) for the Shield area. These renewable groundwater resources, though insignificant compared to non-renewable groundwater, are dispersed in nature, local in occurrence, low in point-source quantity and therefore, difficult to intercept. It is also important to note that in these areas of KSA, where renewable water resources exist, non-renewable groundwater is almost absent. As a result, the reliance is based completely on these renewable resources (MOEP, 2010b).

According to recent estimates, a supplementary potential of 800 MCM/year of these resources can be mobilized. Still, the figure will need to be confirmed through the execution of detailed hydrogeological studies on renewable water resources (i.e. Harrats and Wadi aquifers) in the western part of KSA. Some wadi catchments have been exploited beyond safe yield – namely in Wadi Najran, Wadi Hubunah, Wadi Bisha, Wadi Hamd and the Tihama (MOEP, 2010b).

1.4.3.1 Rainfall and recharge

In KSA, most rainfall occurs in the southwestern part of the country. However, the rainfall and the resulting renewable water resources may vary yearly. The average annual rainfall is less than 150 (mm) in most parts of the country (Zaharani et al., 2011). A country-wide average annual rainfall has also been reported to be less than 100 mm (Omar et al., 2013). The bulk of rain in KSA occurs in the Southern Shield area (up to 500 mm/a). This is the only area in KSA where sustainable use of water resources is possible if good water management is implemented. The rainfall on the northern Shield is less than on the southern shield. Resultantly, the amount of renewable resources is low compared to the Southern Shield, though renewable water resources are the only water resource in this area.

More than 90% of the rainfall commonly evaporates again without contributing to the water resources. The total recharge to all aquifers (principal, secondary, alluvial and basalt) is estimated at 3,958 MCM/year (Abdurrahman, 2006). However, the portion of recharge to shallow alluvial aquifers and those within the basalt layers is limited to approximately 1,196 MCM/year (Abdurrahman, 2006; Zaharani et al., 2011). Based on recent regional studies, the recharge estimate to different aquifers is around 3.4 BCM/year (i.e. 1,276 MCM/year for Saq Aquifer, 1,400 MCM/year for Umm Er Radhuma Aquifer, and the rest for others).

1.4.3.2 Dam storage

Dams can enhance recharge by collecting water and fulfilling the conditions for recharge (induced recharge) locally, while without dams, the water would be lost to evaporation. The government of KSA has made huge efforts to enhance this resource through the construction of multipurpose dams (more than 200 dams in the last two decades), which serve to recharge aquifers, control floods, for irrigation and direct abstraction of water for supply after treatment. Up to 212 dams of different types with a total storage capacity of about 921 MCM were in place in 2009, out of which 540 MCM fell to recharge dams (Al-Saud, 2010). While these dams store runoff water and increase infiltration for recharging groundwater resources, they also prevent flash floods and are used for agriculture and irrigation. Ouda et al. (2013) have reported that the water from flash floods is captured in 260 irrigation dams collecting an estimated 0.6 BCM annually. However, flash floods cannot be considered a source of municipal water. Some of the largest of these dams are located in the Wadi Jizan, Wadi Fatima, Wadi Bisha and Najran. This water is used primarily for agriculture and is distributed through miles of irrigation canals and ditches to vast tracts of fertile land previously fallow.

This potential, however, has not been adequately developed. Improved water management of existing dams and construction of new recharge dams are promising measures to significantly enhance renewable water resources (MOEP, 2010b).

In 2018, 509 dams existed, with a storage capacity of around 2.246 BCM (MEWA, 2018). These dams have been classified as control dams (flood control), recharge dams, and storage dams (potable supply and irrigation use). Over the years, sediment input led to (1) reduced storage capacity and (2) sealing the ground. This reduced the amount of the induced groundwater recharge (MOEP, 2010b).

Most of these dams used to supply drinking water or irrigation are located in the southwestern portion of KSA, with the most precipitation. The location of the existing dams (Potable supply and Irrigation) is presented in Figure 1- 9.

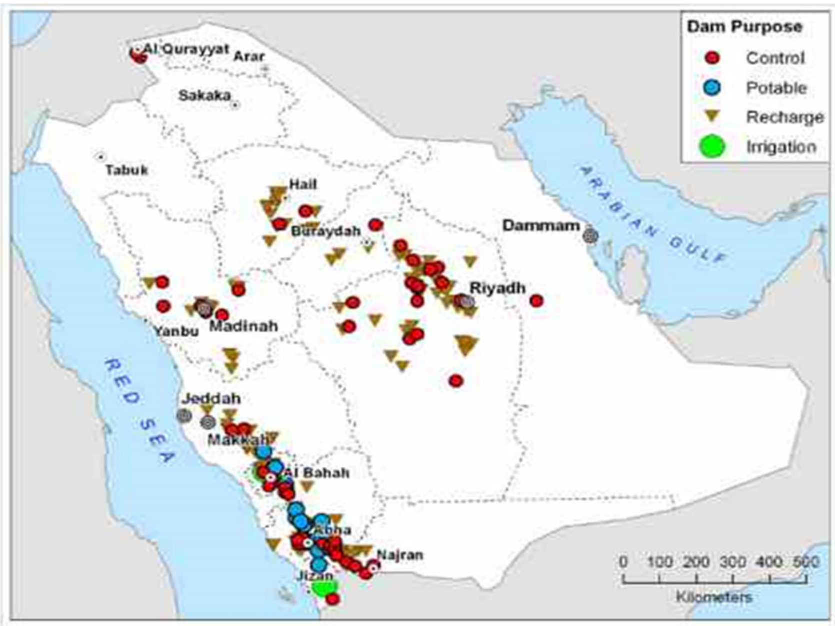


Figure 1- 9 Existing potable supply and irrigation dams (MEWA, 2018)

1.4.3.3 Assessment of renewable water resources

As discussed earlier, non-renewable groundwater resources are limited in areas of the Kingdom where renewable water resources exist, resulting in excessive utilization of these resources being the only resource available. Depending on the rainfall, these resources may vary from year to year; therefore, an accurate estimation may be subject to significant variations. According to recent estimates, KSA's yearly renewable water resources is 2.4 BCM (MOEP, 2010a).

Within the area where renewable water resources exist, the excessive groundwater abstraction has resulted in an exceedance of the safe yield, rendering these areas non-sustainable with water resources (FAO, 2009). In basins where the abstraction has exceeded the safe yield, immediate measures are needed to allow for recovery and long-term sustainable use of these resources.

The situation of renewable water resources has been summarized based on the assessment and strategic plan of the water sector as follows (MOEP, 2010a) and presented in Figure 1- 10.

m. The overexploiting situation of renewable water resources has not changed in the last 25 years. It has rather worsened, although this was addressed in the National Water Plan in 1983;
n. The overall water budget is non-sustainable. A few catchments (Wadi Najran/Wadi Hubunah, Wadi Bishah, Tihama, and Wadi Hamd/Madinah) have a non-sustainable water balance, while others manage to get along with their available water resources;
o. Water shortage in the respective catchments led to drinking water supply from desalinated seawater (e.g. Madinah, Abha) or non-renewable groundwater of the Arabian Shelf (e.g. Najran, planned for Eastern Aseer and Wadi Bishah);
p. Priority is given to agricultural water consumption instead of domestic needs; and
q. Construction of more than 200 dams in the last two decades has increased the availability of renewable resources. However, this potential is not adequately used. Improved management of existing dams and construction of new 'recharge dams' are promising measures to enhance renewable water resources significantly.

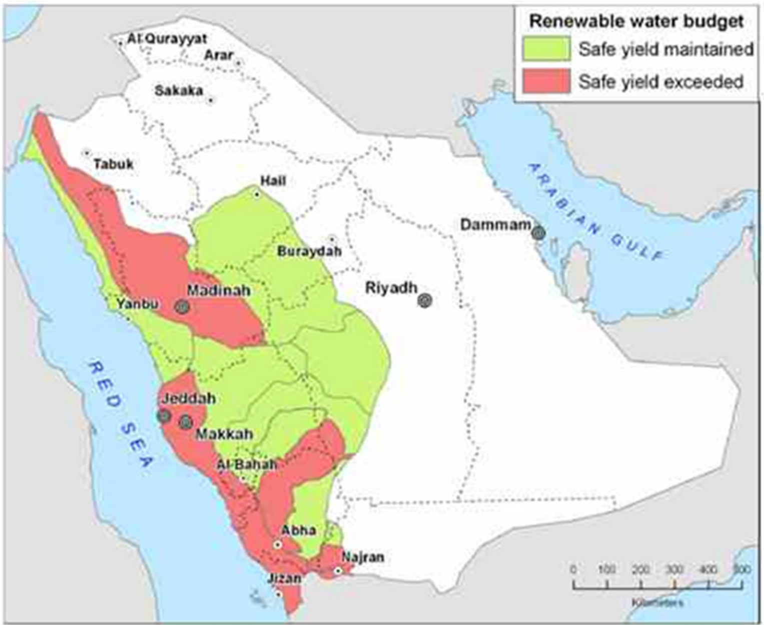


Figure 1- 10 Renewable water resources exploitation in KSA (MOEP, 2010a)

1.4.3.4 Water supply from dams

MoWE is implementing a considerably large program to increase water supply capacity from surface water by adding more dams in the southwestern regions (Jizan, Aseer, and Al Baha) (MoWE, 2013).

In 2018, the drinking water supply sourced from all dams was about 244,400 (m^3/day), limited to Jazan, Asir, Makah and Al Baha regions, as shown in Table 1- 3 (MEWA, 2018).

Table 1- 3 Average water supply from dams (2017)

Region	**Water production (m^3/day)**	**(%)**
Jazan	70,000	0.286
Makah	160,000	0.655
Al Baha	13,500	0.055
Total KSA	**244,400**	**1**

1.4.4 Reclaimed water

Reclaimed water is produced by treating wastewater to a level so that it can be safely reused for non-potable needs such as industrial processes and cooling, agricultural irrigation, landscaping, groundwater recharge, and ecosystem creation or restoration. In 2013, Sewage network coverage in KSA was about 50% of the urban area, and the total treated wastewater volume (secondary or tertiary treatment) is estimated at 3.63 MCM/day as against an estimated wastewater reuse of approximately 0.62 MCM/day (225 MCM/year) (MoWE, 2013). The Ministry of Water and Electricity (MoWE) has launched a major program to expand the sewage grid, reach 70% coverage by 2020 and increase the number of STPs to protect the environment and enhance reclaimed water reuse.

Of the thirteen administrative regions in KSA, Riyadh, Makkah, and Eastern Region produce the bulk of treated wastewater and offer the greatest potential for reuse. KSA aims to expand the availability of reclaimed water significantly and has an ambitious strategic plan to treat and reuse 100% of sewage in all cities of over 5000 persons by 2025.

1.4.4.1 Existing sewage treatment plants

STPs are located in nearly every region and primarily serve large and medium cities. There are a total of 71 STPs that are operational. The current treatment capacity of all STPs in KSA is 4.77 MCM/day (MoWE, 2013), as shown in Figure 1- 11. In 2018, the total number of STPs reached 91, with the total quantities of treated wastewater at 4.56 MCM/day (MEWA 2018).

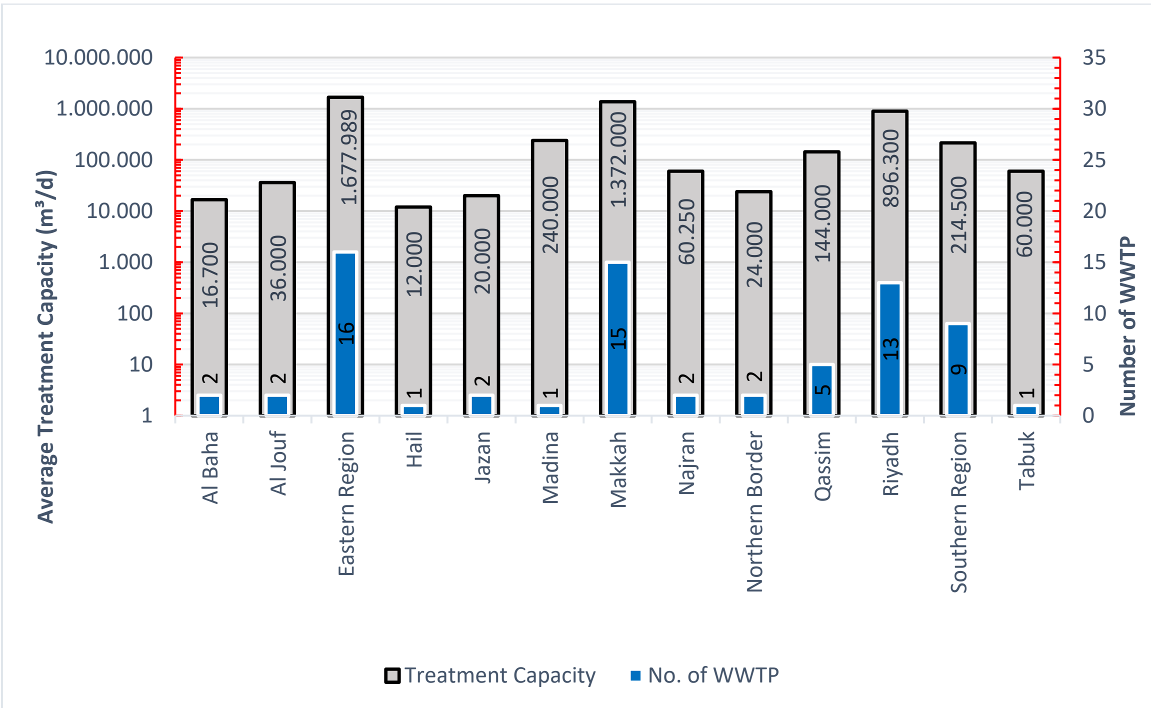


Figure 1- 11 Wastewater treatment capacity (m³/day) by region in 2013

1.4.4.2 Reclaimed water reuse in KSA

The draft MoWE Regional Planning Reports divides the potential reclaimed water uses into five categories: agriculture, landscaping, industry, recreation, and aquifer recharge (KAUST, 2011). The main reuse applications for the treated wastewater in KSA are landscaping and agriculture, while industrial reuse accounts for only 16 MCM/year (MOEP, 2010a). Of the thirteen regions in KSA, Riyadh, Makkah, and Eastern Region produce the bulk of treated wastewater and offer the greatest potential for reuse.

Table 1- 4 Reuse applications by primary and sub-category

Primary Category	Sub-Categories/Examples
Agriculture	· Tertiary treatment is required to meet unrestricted agricultural irrigation, which includes salad crops and vegetables eaten raw and restricted, other crops, and winter and summer cultivation. · Crop examples include cereal, vegetables, melons, watermelon, fruits, citrus, grapes, dates, fodder, and alfalfa.
Landscaping	· Secondary treated and disinfected water suitable for most landscaping in areas without direct human contact. Tertiary treatment is required for use in public parks or other areas where direct human contact is likely. · Applications include city green areas, such as planting trees along roads, turf and grass areas, and public parks.
Industrial	· Secondary treated and disinfected water in some cases (cooling towers, irrigating nurseries and plants surrounding industrial areas). · Very high-quality water for some uses (high-pressure boiler feed); even higher quality.
Recreation	· Not regulated in KSA yet. However, in most cases, tertiary treatment is required for unrestricted recreation. · In Al Jouf Region: small lakes or parks · In Riyadh Region: Wadi Hanifa development, Al Hayer Lakes maintenance.
Aquifer Recharge	· Not regulated in KSA yet. The requirements vary depending on recharge type (direct recharge, sub-surface spreading, etc.). · Used to reduce the scale of drop in the water table. · In Qassim Region: allocated amounts flow through a wadi and mix with stored water from stormwater for aquifer recharge.

Source: KAUST (2011).

KSA aims to expand the availability of reclaimed water significantly. The wastewater flows are projected to increase by approximately 8 MCM/day by 2040 (2.92 BCM/year) and hence will provide essential opportunities to reuse reclaimed water. Currently, key public and private organizations are working in partnership to expand the application of reclaimed wastewater (Kreutzberger et al., 2012).

In 2011, King Abdullah University of Science and Technology (KAUST) published a comprehensive study (KAUST, 2011) of water reuse's role in integrated water resources management. It aimed to identify technology and data gaps that needed to be addressed to support successful reclamation and reuse (as well as business opportunities) where reuse would support sustainable and integrated water management objectives.

The study highlights several uses for reclaimed water in managed aquifer recharge strategies in KSA. Such uses involved storage, treatment and recovery. The reclaimed water could be used to store available excess water for future use, thus serving as a treatment step in a multiple-barrier approach to reclaimed water reuse. Also, it could be used to establish a salinity barrier system to prevent saltwater intrusion into an aquifer.

Managed aquifer recharge is feasible in four regions (i.e., Greater Riyadh, Madinah, Makkah, and Greater Dammam area). Each area offers unique opportunities to enhance water resources management using reclaimed water for aquifer management. The 2013 wastewater reuse by region is presented in Figure 1- 12.

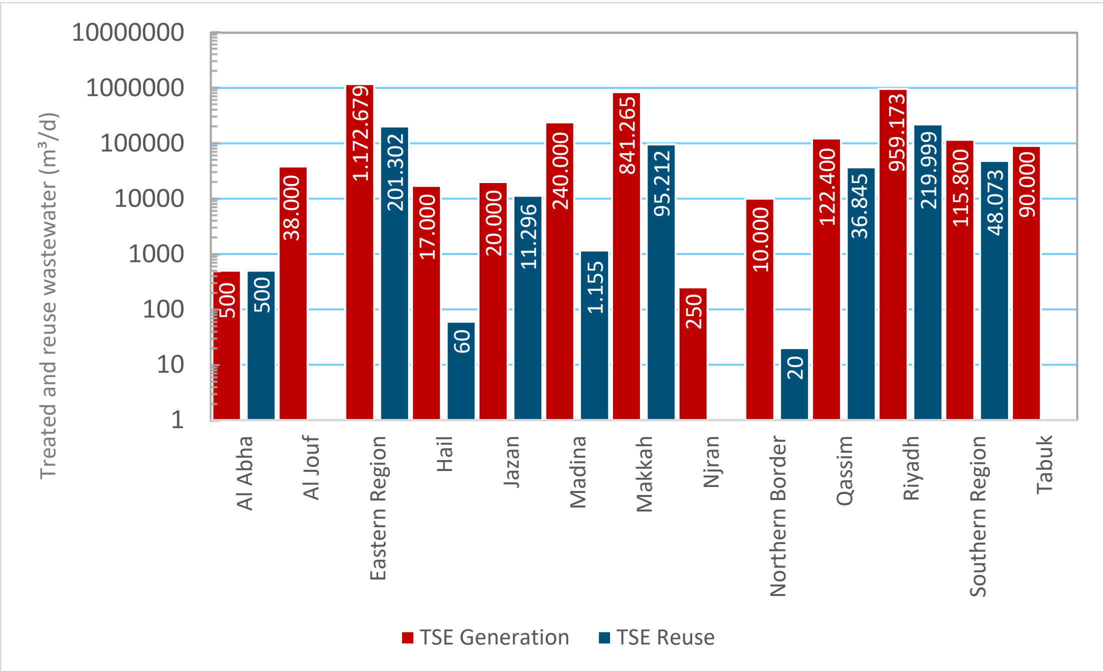


Figure 1- 12 TSE generation and reuse (MoWE, 2013)

Consistent with the population disposition across KSA, the major wastewater treatment plants (i.e. with relatively greater treatment capacity) are concentrated in the major population centres on the Red Sea Coast, the Arabian Gulf coast and the capital city of Riyadh, as shown in Figure 1- 13. Though the potential for the reuse of reclaimed water exists around every major city in KSA, the greatest benefit could be drawn by exploiting this resource in the vicinity of Riyadh city, Al Kharaj, within the Riyadh-Hail Corridor around Buraidah and Unaizah and in the vicinity of Tabuk.

These areas are the major agricultural centres where the signs of deterioration in groundwater quality and quantity are already evident due to excessive groundwater abstraction for large-scale industrial agriculture. In these areas, there is competition between groundwater uses for municipal supply and agricultural use. Any reused wastewater is likely to help reduce the burden on already stressed groundwater in these areas.

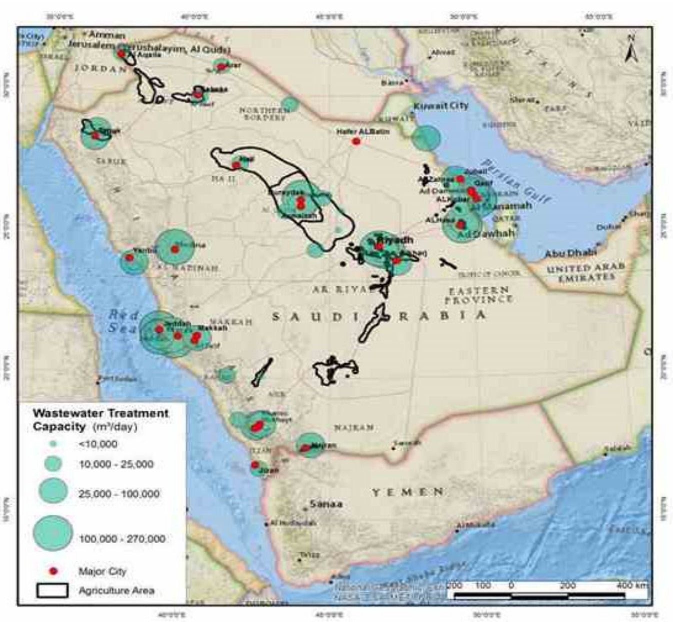


Figure 1- 13 Wastewater treatment plants – location map

1.5 Water Use Interaction with Water Resources

Following paragraphs will present the three water users (municipal water, industrial and agriculture) and their respective interaction with water resources.

1.5.1 Municipal water use

The municipal water supply across KSA relies more on desalinated water than groundwater, though mostly for the major population centres in the coastal regions. Based on MoWE, the total municipal water supply in 2013 is estimated at 2.82 BCM (7,726,027 m^3/day), with desalinated water and groundwater accounting for 57.6% and 40.6%, respectively. The supply from surface water (dam storage) accounts for a meagre 1.8% of the total supply, as shown in Figure 1- 14 (MoWE, 2013).

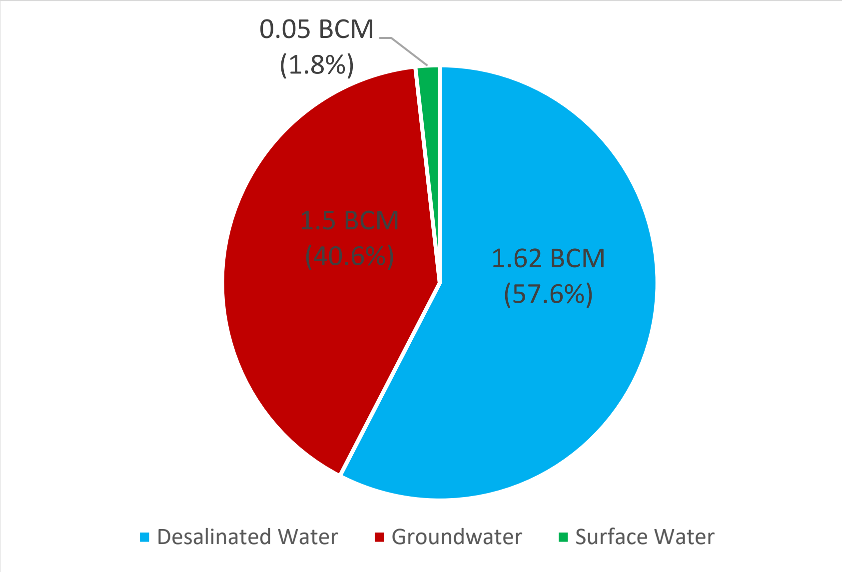


Figure 1- 14 KSA total municipal water supply (2013) by source

The municipal supply in KSA generally conforms to the water resource availability pattern across the Kingdom, apart from a few exceptions (e.g., Riyadh). The coastal regions receive most of their municipal supply from desalination plants on the respective coasts. In contrast, most inland regions (Northern region, Al Jouf, Hail, Najran, Tabuk) rely mainly on the groundwater supply from the MoWE well fields. Only Baha, Jazan and Asir regions receive some of the supply from surface water (Dams). The capital city Riyadh though located inland on the Shelf, has the supplemental supply from east coast desalination facilities to keep up with its increasing water demand. Per region, the percentage contribution of each water source to the total 2013 supply is presented in Figure 1- 15 (MoWE 2013).

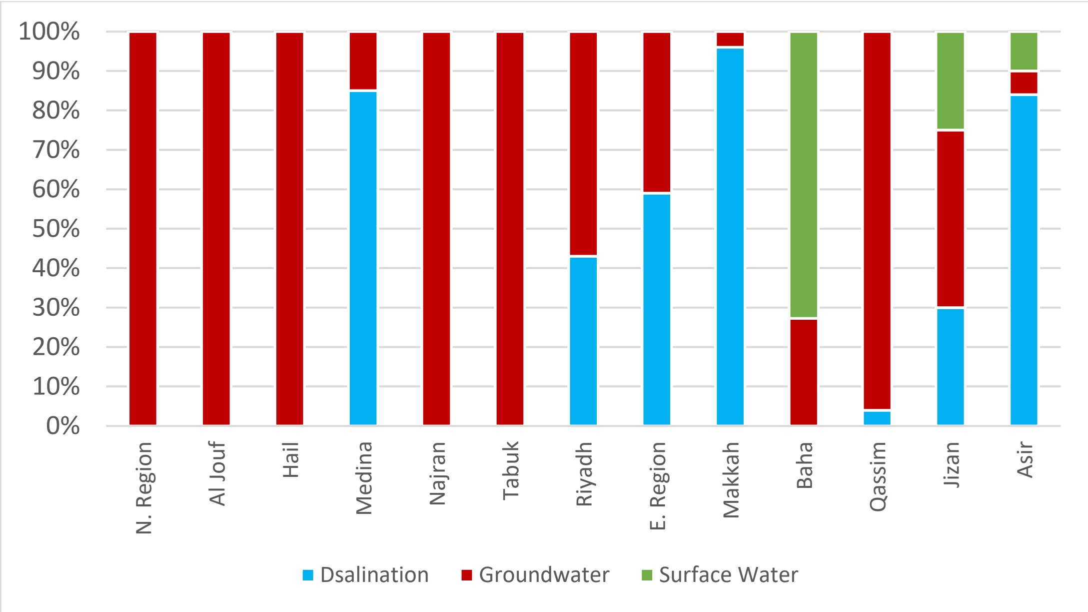


Figure 1- 15 Water supply by source for the thirteen regions in KSA (2013)

Given the substantial oil wealth, water is provided almost for free. Despite improvements, service quality remains poor. For example, in Riyadh, water was available only once every 2.5 days in 2011, while in Jeddah, it is available only once every 9 days. Since 2000, the government has increasingly relied on the private sector to operate water and sanitation infrastructure, beginning with desalination and wastewater treatment plants. Since 2008, urban water distribution systems have been gradually delegated to private companies.

The MoWE municipal water demand forecast developed in the national master plan for municipal water supply is based on supply-side management with a fixed per capita approach, in which the per capita water allocation for each city is set according to the city size depending upon its population as shown in Table 1- 5. This approach assumes that the water demand is controlled by the supply, is directly proportional to population growth and that per capita allocation will not change during the next 25 years.

Table 1- 5 MoWE criteria for water demand forecast

Category	Major Cities	Medium Towns	Small Villages
Population	More than 85,000	Between 5,000 and 85,000	Less than 5,000
Target supply L/capita/day	250	200	150

This per capita water allocation includes residential and non-residential water components and losses in distribution and is used as the design criteria for water production facilities.

Table 1- 6 shows the Key Performance Indicators (KPIs) of the water supply sector in KSA for 2013:

Table 1- 6 Municipal water supply sector KPIs (2013)

Population (Pers.) 2013	**27. 25 Million**
Total production[8] (Mm^3/day)	7.73
Desalination (Mm^3/day)	4.45
Groundwater (Mm^3/day)	3.14
Surface water (Mm^3/day)	0.14
Gross Per capita[9] L/person/day	150 - 400
Householders receiving continuous service (24/7)	≤ 30 %
Leakage (%)	35% to 20%
Connection to water supply %	<80%
Connection to sewage %	around 50%
Treated wastewater (Mm^3/day)	3.63
Reclaimed water (Mm^3/day)	0.61

In 2018, the total municipal water consumption was approximately 3.39 BCM (9,293,151 m^3/day). Of this consumption, 85% is residential, and 15% is nonresidential, with desalinated water and groundwater accounting for 63% and 37%, respectively (MEWA 2018). MEWA does not account for the supply from surface water (dam storage) out of total consumption.

1.5.2 Agricultural water use

The main agricultural centres in KSA are located within the Shelf region. The Hail-Riyadh corridor represents the core region for industrial agriculture. In addition, recent industrial and agricultural developments include Wadi Ad Dawasir, Tabuk and Jawf regions near the borders with Jordan. Traditional agricultural areas are found around Riyadh, in Wadi Hanifah and near Al Kharj, in Wadi Al Sahba and the palm tree oasis of Al Hofuf, in the Eastern Region. On the Shelf, the water supply for irrigation is almost entirely from non-renewable groundwater resources. As many agricultural centres are located near or around cities and towns, the agricultural water supply competes with municipal drinking water supply for the same non-renewable resource. The main agricultural areas within the Shield region and the Red Sea Coast are in the southwestern Asir and Jizan regions. Agriculture water demand for irrigation is met by renewable water resources from shallow aquifers and surface-runoff (dams) harvesting. In some mountainous areas, especially within the Asir Region, agricultural land is rain-fed and does not require irrigation (MOEP, 2010a).

The current agricultural water consumption on the Shelf is estimated to be around 13 BCM/year, sourced almost entirely from non-renewable groundwater. In contrast, in the

[8] Total production volume (7.73 Mm^3/d) does not include private wells and tankers production (self supply) estimated at around 330 000 m^3/d. Self supply could cover 5% to more than 30% of water demand depending of water distribution grid coverage and water availability.

[9] Gross per capita: Production volume / population which includes leakage, residential and non residential consumption

Shield area, it is estimated that agriculture sector utilization is around 3 BCM/year (MOEP, 2010a).

The Agriculture Development Fund (ADF) has carried out, in association with MoWE, a comprehensive study and strategic plan for water use in agriculture. The study indicates that the agricultural sector in the KSA is ranked very low concerning irrigation efficiency, averaging 53%. However, modern irrigation methods such as centre pivot irrigation or sprinkler irrigation are used at places (ADF, 2013). This results in approximately 5.65 BCM/year of water wasted in KSA due to low irrigation efficiency. Several water conservation measures have been identified to reduce water consumption in agriculture to 5.5 BCM/year by 2030.

Water conservation measures include irrigation systems and equipment, crop selection, livestock selection, agro-industrialization, workforce training and awareness.

Figure 1- 16, extracted from the mentioned study, shows the regional view of current consumption and target budget.

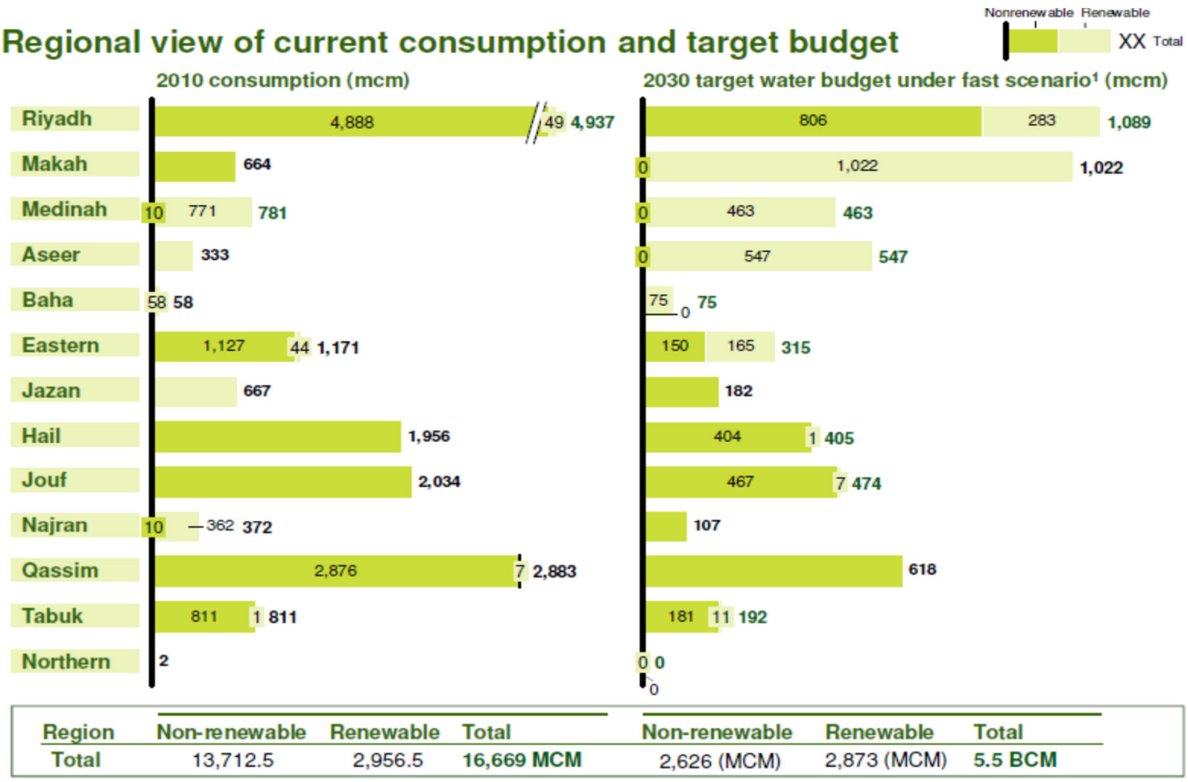


Figure 1- 16 Regional view of current consumption and target budget

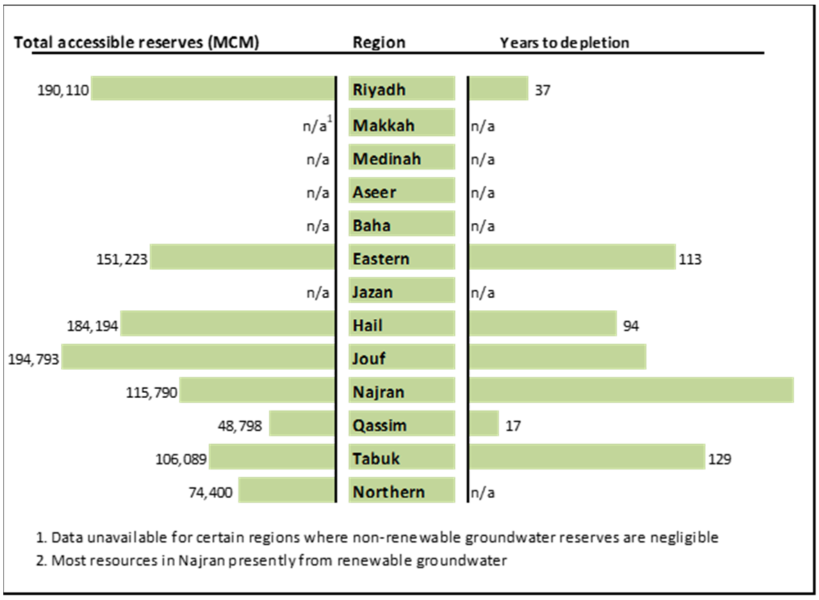
The study also indicates that Riyadh, Qassim, Al Jouf, Hail and eastern regions represent KSA's top 5 consuming regions. These regions cover approximately 78% of the cultivated area and produce almost ~76% of the agricultural output in KSA. The study has also estimated the accessible supply for each region based on the availability of resources within a 200 km distance of the demand centres and the assumption that 40% of the reserves will be inaccessible due to water quality deterioration. The estimations suggest that accessible reserves (all regions combined) total approximately 1,019 BCM. If the consumption rates of 2010 continue, it is estimated that these reserves will disappear as early as 17 years in Qassim. However, they may last longer in other regions, as shown in Figure 1- 17.

The agricultural water demand in KSA began rising rapidly just before 1980 when development in irrigated agriculture was promoted by direct and indirect investment and soaring government subsidies to farming. It almost tripled the water used for agricultural irrigation, from around 6.8 BCM in 1980 to nearly 23.3 BCM in 2000. Withdrawals continued at very high levels until 2004, after which they started to decrease due to declining water levels and the Government's enforcement of a series of measures to mitigate the undesirable effects caused by the agriculture policy. Groundwater abstractions for agriculture have increased since 2010, reaching approximately 17 BCM in 2012 due to switching to high water-consuming fodder crops (alfalfa) from wheat (MoWE, 2013).

In 2010, about 7,730 km^2 were being used for agriculture nationally. 6,850 km^2 were under irrigation, mainly in four regions (Riyadh, Jouf, Ha'il and Qassim). Current output tonnage is 6.8 million tons and consumes 16.7 (BCM/year) of water nationally, representing ~83-84% of national water demand. Five (5) of the thirteen (13) regions (Riyadh, Jazan, Qassim, Jouf and Ha'il) contain 78% of the cultivated area and represent the majority of the agricultural output (76%) and hence are the top 5 water consuming regions (ADF, 2013). The current agricultural water consumption on the Shelf is estimated to be around 13 BCM/year, sourced almost entirely from non-renewable groundwater (MOEP, 2010).

In December 2013, The ADF completed, in association with MoWE, a comprehensive study and strategic plan for water use in agriculture. The study indicates that the agricultural sector in KSA is ranked very low regarding irrigation efficiency, averaging 53% for KSA, even though modern irrigation methods such as centre pivot irrigation or sprinkler irrigation are in use at places. This results in approximately 5.65 BCM/year of water wasted in KSA due to low irrigation efficiency.

The ADF study has also estimated the accessible supply for each region based on the availability of resources within a 200 km distance of the demand centres and the assumption that 40% of the reserves will be inaccessible due to water quality deterioration. The estimations suggest that accessible reserves (all regions combined) total approximately 1019 BCM. If the consumption rates of 2010 continue, it is estimated that these reserves will disappear as early as 17 years in Qassim. However, they may last longer in other regions, as shown in Figure 1- 17.



Source: Agricultural Development Fund, ADF (2013)

Figure 1- 17 Total accessible reserves and years to depletion

The agriculture water demand forecast model has not been developed since it is out of this scope and requires an in-depth analysis of many factors on crop type, number of crops, irrigation requirements, and irrigation efficiencies, and requires voluminous data. Reliance has been placed on the excessive information on agricultural water use in the last few years. The ADF (2013) study was completed to appraise KSA's water and agriculture situation rapidly.

The agricultural water demand forecast developed by the ADF has been used to underscore the importance of water demand management in broader terms.

The ADF forecast is based on conservation measures and improving irrigation efficiency. Compared with the average agricultural water consumption over the last 6 years (2007-2012), the ADF forecast indicates the potential benefits of tackling agricultural consumption as a very high priority to ease challenges related to municipal demand management. The ADF forecast assumes that involving a sequence of conservation measures and improving irrigation efficiency as follows:

r. The crop water requirements in 2010 were calculated at 8.85 BCM/year against an estimated consumption of 16.7 BCM/year resulting in an overall 53% efficiency. Achieving 85% efficiency would save 5.6 BCM, an improvement of ~35% from the current status. A more conservative target of 75% efficiency will translate into savings of 4.3 BCM/year;
s. A 20% crop migration at the current efficiency will save 1,048 MCM of water. If newly converted areas are pushed to the efficiency frontier (85%), the savings will be ~ 1,300 MCM/year;
t. In-the-pipeline projects will allow renewable supplies used in agriculture to be pushed higher, reducing the stress on non-renewable resources. It is expected that an additional 700 MCM/year of wastewater and 640 MCM/year of renewable surface water and groundwater will be available for agricultural use.

Although much remains to be accomplished to transform the agricultural sector, some of these measures are already under implementation (ex., wheat/cereals reduction), and others are waiting for government approval (ex., fodder initiative). Agricultural water use can be reduced considerably whilst maintaining agricultural GDP and farmer incomes and assuring farmers about their future. If all these measures were implemented, about 10 BCM/year of irrigation water could be saved annually, bringing the total irrigation consumption under 7 BCM/year. Increasing the average irrigation efficiency from 50% to 75% (a technically possible scenario) alone could reduce agricultural withdrawals from 17 BCM/year (current volume) to 11.3 BCM/year, a saving of 5.7 BCM/year (MoWE, 2013).

The ADF best case considers the following:

u. Wheat/cereals will be phased out completely by the end of 2015;
v. The Animal Feed Plan is expected to replace most domestic animal feed with imports, reducing local production to a minimum. There may still be 600 (km^2) of fodder cropping to continue using around 2.0 BCM/year of rainfed water and treated wastewater;
w. High-value crops will continue to receive support, provided that improvements in irrigation efficiency are implemented. Annual water demand for these crops is limited to 5.5 BCM/year, of which 60% would be renewable water and 40% non-renewable.

Figure 1- 18, based on ADF- Best case scenarios, indicates that considerable savings in agricultural water consumption can be realized if the recommendations of the ADF study are adopted. The ADF best-case scenario is based on the assumption of the status quo as it is hard to predict the progress in implementing these recommendations and the fact that if the recommended measures are implemented, any further reduction would be very challenging.

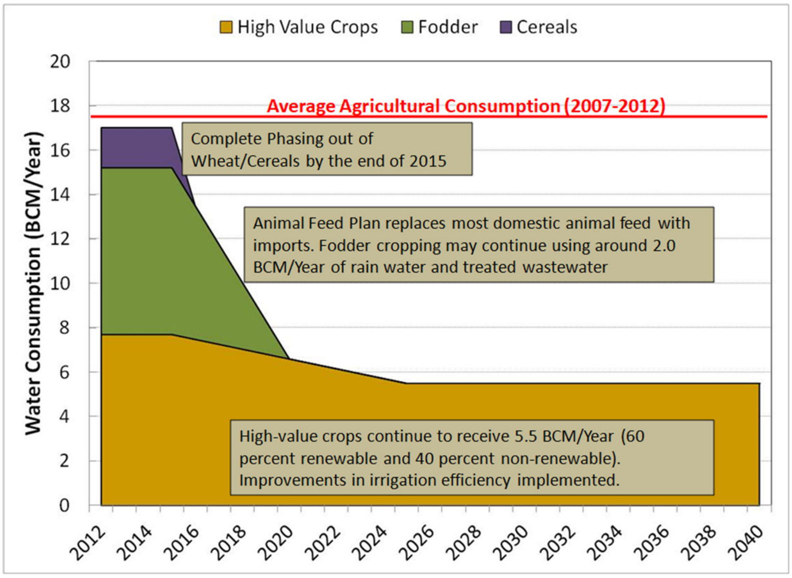


Figure 1- 18 Projected agricultural water consumption (ADF-Best Case Scenario)

Unfortunately, the ADF study was not implemented, leading to the increased agriculture water consumption of 21.39 BCM in 2018 (MEWA, 2018).

1.5.3 Industrial water use

In KSA, most of the industrial activity is concentrated in the 20 industrial cities; hence, industrial consumption, in a way, is separated from municipal consumption and covered mainly by nonrenewable groundwater. Industrial consumption primarily relates to water consumption by different industry types for various processes specific to each industry and mining and oil extraction activities. The MEWA data show increased industrial use over the years due to industrial expansion and economic development (MEWA, 2016), as shown in Figure 1- 19. Main industrial water consumption is covered by groundwater and private desalination plants.

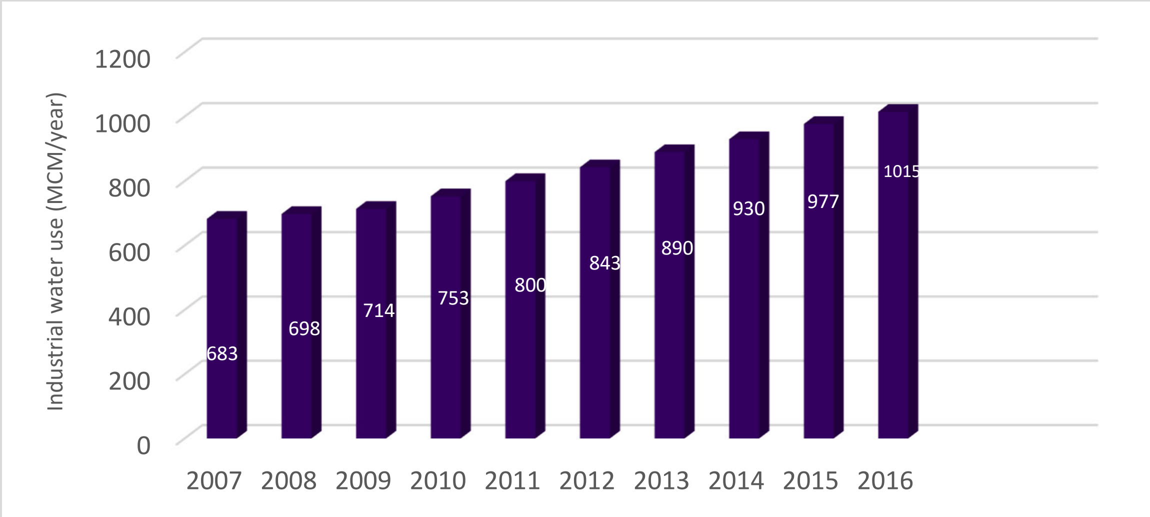


Figure 1- 19 Industrial water use in KSA (2007-2016)

The historical trend in Figure 1- 19 above indicates a progressively increasing trend in industrial water consumption. Industrial consumption has steadily increased from 683 MCM/year in 2007 to 843 MCM/year in 2012, indicating a net increase of approximately 160 MCM over 5 years (an increase of 23.4% or an annual growth rate of 4.3%). Projecting the trend to 2040 indicates that the total yearly industrial water consumption is likely to reach approximately 1,746 MCM by 2040, as shown in Figure 1- 20.

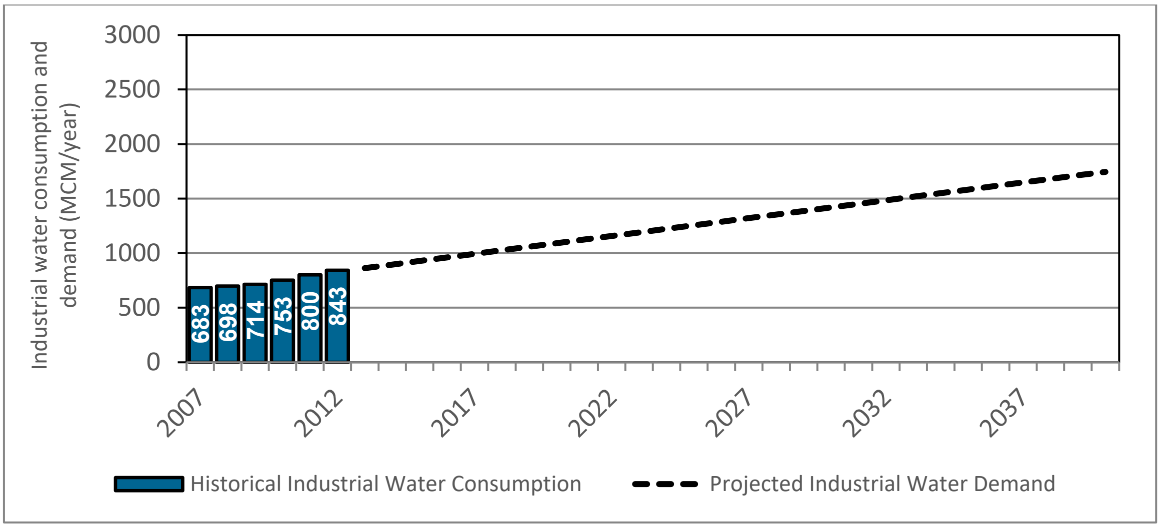


Figure 1- 20 Industrial water consumption & demand in KSA (2015-2040)

1.6 Water Budget Estimation

According to a MoWE estimate, the total water usage in KSA in 2012 was about 21 BCM. The major contribution is from non-renewable groundwater, which accounts for approximately 15.45 BCM (74%) of the total supply from different sources. In addition, renewable water resources and desalinated water contribute about 3.69 BCM (18%) and 1.54 BCM (7%), respectively. The contribution from reclaimed wastewater is minimal, approximately 1% (MoWE, 2012), as shown in Figure 1- 21.

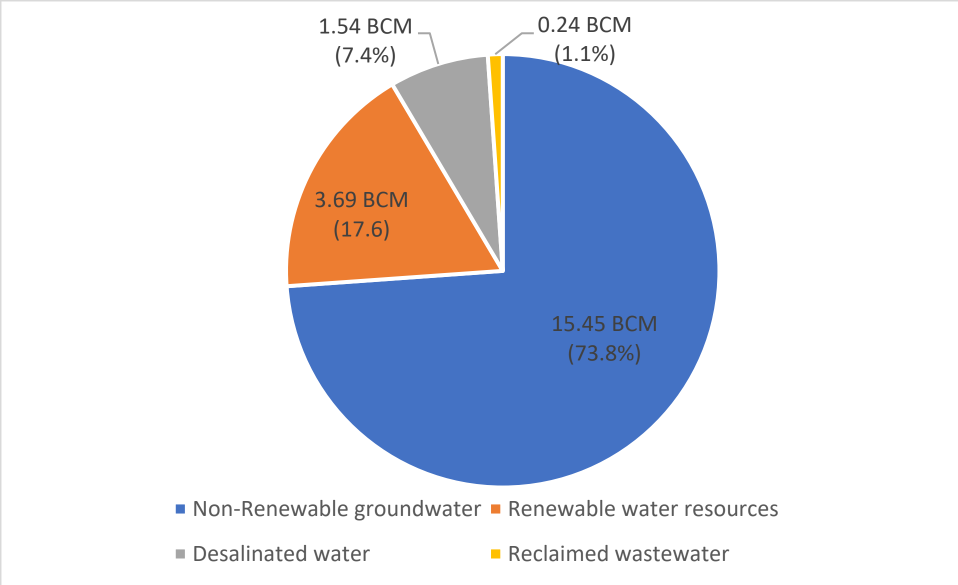
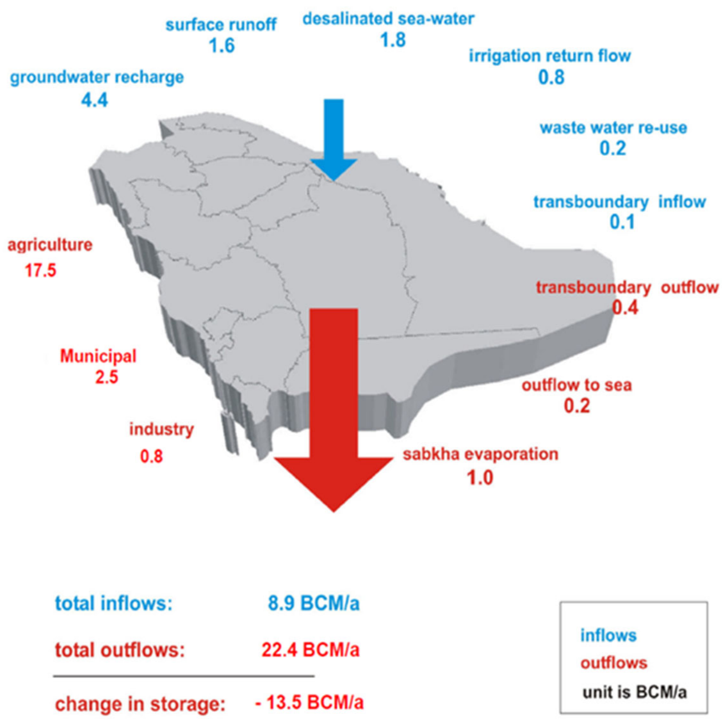


Figure 1- 21 Total water use in BCM by source in KSA (2012)

This level of consumption puts enormous pressure on water resource sustainability as the annual water budget of KSA falls short by approximately 13.5 BCM. Figure 5-3 provides KSA's yearly overall water budget for 2012, once all natural and anthropogenic inflows and outflows (including natural transboundary outflows) are accounted for. It is noted that this shortfall includes about 1.8 MCM/year of inflows from desalination, which, if excluded, would increase the shortfall to 15.3 BCM/year.

KSA’s water budget, as in Figure 1- 22 for 2012, includes all natural and anthropogenic inflows (including desalinated sea water) and outflows across the KSA boundary. The water budget is negative as the outflows exceed the inflows by 13.70 BCM. The deficit is met by withdrawing water from the non-renewable groundwater resources, which stresses this diminishing resource and affects water resources' sustainability. It is noted that the budget deficit includes about 1.6 MCM of inflows from desalination, which, if excluded, would increase the shortfall to approximately 15.2 BCM. Moreover, the water budget highlights the need to implement a supply/management system based on the IWRM approach.



Source: Modified from MOEP figure (2010c).

Figure 1- 22 KSA water budget (2012)

The 2008-2018 estimates of water consumption in KSA indicate that approximately 201 BCM/year of water is utilized by various sectors (agricultural, Industrial and municipal). There has been a steady increase in water consumption in the last few years, especially in the agricultural sector, despite realising that agricultural water use at the current rate is not sustainable, as shown in **¡Error! No se encuentra el origen de la referencia.**.

Figure 1- 23 Sectoral water consumption in KSA (2007-2012)

1.7 Supply Side Options for Water Sector

Water availability in the quantity and quality necessary for the use and at an affordable price plays a significant role in achieving the competitiveness of the KSA economy and the quality of life of its citizens. The extreme scarcity of renewable resources in KSA does not allow for achieving sustainability in classical terms – as a long-term equilibrium between renewable resources and utilization is impossible (MOEP, 2010a). Based on the principle that future generations have equal rights to water as the present generation, KSA's vision is to maximize non-renewable resources availability for essential needs (i.e., drinking water demand, vital economic activities and agriculture heritage). Currently, about 50% of the population of KSA depends on non-renewable groundwater resources. KSA has a significant agricultural sector, but current agricultural practices are unsustainable. They rely on mining non-renewable groundwater, with more than half of this water wasted on low-value crops. Depleting these resources by agriculture would mean an increased dependency on desalinated water, a more vulnerable and expensive option (MOEP, 2010).

Chapter 2

WATER QUALITY, SECURITY AND ENVIRONMENTAL and SOCIAL IMPACTS

2 WATER QUALITY, SECURITY AND ENVIRONMENTAL AND SOCIAL IMPACTS

This section concerns the security and quality of water supply and environmental and social considerations. The section also deals with the relevant topic of risk assessment for water supply. Reflecting that security of the water supply has close linkages with the risk assessment.

The term “water security” aims to capture the complex concept of holistic and sustainable water management and the balance between resource protection and resource use. A holistic approach requires balancing the competing demands on the resource, including domestic, municipal, agricultural, industrial and environmental. It also requires balancing protecting the resource (ground and surface water) and meeting social needs and economic development. Effective water resources and services management must reflect the interaction between these different demands and be coordinated between and across sectors. Instead of fragmentation and conflict, competing sectoral interests and responsibilities for the whole water sector can be managed using a holistic and integrated approach. Without integrated water resource management (IWRM), water use and services may not be sustainable, leading to increased water insecurity.

2.1 Water Quality

2.1.1 Groundwater quality

Each principal and secondary aquifer has been characterized concerning total salinity, a general parameter of the overall water quality. The total salinity in these aquifers is highly variable spatially and has also experienced a temporal change, attributed to various physicochemical processes directly or indirectly linked to non-sustainable (excessive) abstraction. The current state of knowledge on the salinity distribution indicates that the groundwater within the principal and secondary aquifers can be broadly classified as fresh, fresh to slightly brackish, fresh to brackish, fresh to moderately saline, fresh to saline or slightly brackish to saline depending upon the spatial location.

The groundwater salinities on the Shelf increase from west to east in areas near the Arabian Gulf coast. The high salinities in most parts of the coastal area are probably not caused by modern seawater intrusions in the first place. Still, they may represent a mixture of ancient meteoritic recharge and even older connate waters (MOEP, 2010c). Groundwater salinities can also exceed the limit of 2,000 mg/L near the outcrop areas, caused by large groundwater abstractions for agricultural purposes (MoWE, 2008). This manmade increase in salinity leads to a reduction of the exploitable groundwater resources for domestic supply.

A study of the Umm Er Radhuma aquifer system (i.e. an aquifer system comprising four partly interconnected aquifers – Neogene aquifer complex, Dammam aquifer complex, Umm Er Radhuma Aquifer and the Aruma Aquifer) indicates that the total salinities tend to be high and generally increase within the whole aquifer system from < 1000 mg/L in the outcrop areas to > 5000 mg/L in the coastal areas. The west-east trend of salinity increase is more pronounced in deep aquifers (Aruma and Umm Er Radhuma) but less distinct in shallower aquifers

(Dammam and Neogene aquifer complex). The shallow groundwater within the outcrop areas of Aruma and Umm Er Radhuma aquifers is relatively young, containing a relatively high proportion of Calcium and Bicarbonate, representing young meteoric recharge. Groundwater within the central parts of the Aruma and Umm Er Radhuma aquifers is older and dominant in sulfate, chloride and calcium ions due to long contact times with respective formations. Groundwater in coastal areas of both aquifers is dominant in chloride and sodium ions. On the contrary, the groundwater within the Dammam and Neogene aquifer complex does not exhibit this distinct chemical evolution along the flow system due to higher heterogeneity and surface influences (MOEP, 2006).

The study of the Saq aquifer system (i.e., the Saq and the overlying aquifers) indicates that though there has been no significant change in the overall water quality since the development of strong groundwater extraction, there is evidence of localized groundwater pollution in areas with extensive agricultural activity (MoWE, 2008b). This includes:

x. High nitrate levels in some agricultural wells;
y. Mixing of good quality water from the Saq aquifer with poor quality water from the overlying Kahfah Formation, most likely due to poor well design, as observed in parts of the Qassim region; and
z. High salinity levels near wadi beds spreading areas indicate pollution from the wadi beds or nearby sabkhas. As these saline waters are attracted into deep depression cones, they further deteriorate water quality.

However, the most alarming impact of groundwater abstraction on groundwater quality is related to radionuclides. Due to its geological nature, radionuclides are naturally present in some aquifers. The high radionuclide concentrations frequently occur in agricultural areas where excessive groundwater withdrawals cause modification of flow patterns and the mobilization of radionuclides attributable to aeration of formerly anoxic aquifer sections. It results in a significant change in the local hydrochemical environment or the induction of cross-formational flow due to a hydrostatic pressure drop. Data on radionuclide activity in the groundwater of Qassim and Hail regions indicate a positive correlation of radionuclide activity and a decrease in water levels (MoWE, 2008b). Though poorly understood, this correlation is hypothesized to be because of the hydrogeological conditions resulting from the excessive water level decline. It favours convective and diffusive transfer of radionuclides associated with flow patterns, leakage through layers and/or compaction of these layers caused by the decrease of the piezometric head in the adjacent aquifers and release of water.

A published literature (Schubert et al., 2011) indicates that elevated radioactivity concentrations exist in Saudi Arabian sandstone aquifers as follows:

aa. Lower Wajid Aquifer: 10 samples out of 11 indicated an exceedance of the World Health Organization (WHO) guideline level of 100 mBq/L for 228Ra activity.
bb. Upper Wajid Aquifer: 24 samples out of 30 indicated an exceedance of the WHO guideline level of 100 mBq/L for 228Ra activity.
cc. Saq Aquifer: 226Ra and 228Ra activities are high. Of the 34 samples, 27 and 7 exceeded the corresponding threshold values for 226Ra and 228Ra, respectively.
dd. Wasia- Biyadh Aquifer: Concerns have been raised concerning radioactivity levels.

2.1.2 Seawater quality.

Though an alternative water source in supply terms, water supply from seawater desalination plants have associated potential adverse environmental impacts. These are mainly related to discharges of concentrate (reject brine) and waste heat which may impair coastal water quality and affect marine life. Of the exhaustive list of potential impacts, the most obvious ones include an increase in salinity (5-10 ppt above ambient conditions), localized increase in seawater temperatures (about 7-8 ^{o}C above ambient conditions), contamination due to the release of toxic substances such as chlorine, flocculants such as Ferric Chloride (FeCl3), Aluminum Chloride (AlCl3), anti-scale additives such as Sodium hexametaphosphate (NaPO3) and acids such as sulfuric acid (H2SO4) or Hydrochloric acid (HCl) used for pH control (Dawoud and Al Mulla, 2012).

2.2 Environmental and Social Considerations

The different types of water resources currently used in KSA have varying environmental and social impacts. In 2012, most water withdrawn came from fossil, deep aquifers (74%), while renewable water accounted for 17.6%, desalinated water 7.4% and reused treated wastewater 1.1% (MoWE, 2012). Compared to other water resources, wastewater reuse has a low environmental footprint and is one of the most sustainable resources.

On the other hand, desalination plants generate significant environmental and social impacts. Because the technology (mainly thermal process) requires high-energy consumption and contributes to climate change by generating a large amount of CO_2, the seawater intake and the release of brine water affect the seawater properties and the marine ecosystem the plant vicinity. As the life span of many desalination plants is ending, a retirement profile of existing plants over the optimization of renewable and non-renewable groundwater would benefit the environment as long as the groundwater is used more efficiently and sustainably.

Optimizing and finding the best economic, social and environmental equilibrium between the different water resources would lead to sustainable and reliable use of this resource and provide long-term water supply security.

2.3 Security of Water Supply

In today's age, water security has attained a critical dimension for sustainable development in the developing and developed world. The second World Water Forum held in Hague in 2000 emphasized that access to safe and sufficient water and sanitation are basic human needs and essential to people's health and well-being. The Ministerial Declaration on Water Security in the 21st Century, adopted by some 120 ministers that attended the Second World Water Forum, noted that meeting the basic water needs (securing food supplies, protecting ecosystems, sharing water resources, managing risks, valuing water and governing water wisely) are the main challenges of 21st century (World Water Council, 2000).

In 2012, a report on Global Water Security was commissioned by US National Intelligence Council (National Intelligence Council, 2012). The report considers the implications of global water security as affected by water problems (shortages, poor water quality, floods, population, climate change, continued economic development etc.) over the US national security interests over the next 30 years. The report also reiterates that the demographic and economic development pressures will lead to significant challenges in coping with water problems for many countries in North Africa, the Middle East, and South Asia. The key findings of the report include the following:

ee. During the next 10 years, many countries will experience water problems—shortages, poor water quality, or floods—that may lead to instability, state failure and increased regional tensions;
ff. Fresh water availability will not keep up with demand in the absence of effective management of water resources; and
gg. Water problems will hinder the ability of key countries to produce food and generate energy, posing a risk to global food markets and constraining economic growth.

KSA is the largest arid country in the Middle East, covering nearly 2.24 million km^2 of the Arabian Peninsula with limited surface water resources (absence of perennial rivers, streams or lakes) due to low and irregular precipitation, high evaporation rates (Gutub et al., 2013).

KSA suffers severe water scarcity and mainly depends on non-renewable groundwater resources, for which the finite nature and uneven distribution is a geographic reality. KSA is under severe water scarcity. The per capita water availability is estimated at 98 m^3/per inhabitant per year (Drafaoui and Al Assiri, 2010), which is less than the 1000 m^3/per inhabitant per year according to the existing international water scarcity index (United Nations Development Programme, 2006). The increasing water demand for the expanding population needs to be satisfied on the one hand, while the expanding economy requires an increased energy and water supply. Most industries that drive economic growth require reliable freshwater supplies in some part of their process. As a higher fraction of the population becomes wealthier, the change in the standard of living results in increased water demand. Competing demands on water resources for different uses underscore the importance of a sufficient, reliable, secure water supply.

Over the past decade, there has been an increase in awareness among policy makers, regulators, water managers and, to some extent, the general public on the threats to water security. Studies completed in the past decade by the Ministry of Water and Electricity (MoWE), the Ministry of Economy and Planning (MoEP), and the Ministry of Agriculture (MoA) highlighted that groundwater extractions were at unsustainable levels, as well as the deterioration of groundwater quality across KSA. This poses a severe threat to water resource availability and sustainability. Recognizing this, MoWE developed the National Water Strategy (NWS) in 2013 (MoWE, 2013), which aimed to deliver a “sustainable use of water with a focus on conservation, efficiency and security”. The guiding principle outlined in the NWS related to water security is that the “water supplies should be assured through water management and should be protected in case of natural or geopolitical disasters”.

2.3.1 Water security –definition and concept

The definition of water security has evolved over the past two decades. A few definitions focus on elements relevant to one or more specific disciplines like engineering and environment, while others are much broader, encompassing various dimensions. The first comprehensive definition of water security was introduced during the Second World Water Forum in 2000

(Norman et al. 2010). It states, "Water security at any level from the household to the global means that every person has access to enough safe water at an affordable cost to lead a clean, healthy and productive life while ensuring that the natural environment is protected and enhanced”.

Another definition presented by Norman et al. (2010) defines water security as “sustainable access, on a watershed basis, to adequate quantities of water, of acceptable quality, to ensure human and ecosystem health”. The United Nations defines water security as “the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water-related disasters, and for preserving ecosystems in a climate of peace and political stability” (United Nations University Institute for Water, 2013).

While there are many variants of the definition, the concept of water security, as it has evolved, has associations with long-established concepts, notably national security, human security, and food and energy security. The concept of water security encompasses the following key themes which can help structure the development of a pragmatic, yet inspirational, metric framework (Mason and Calow, 2012):

hh. Water security goes beyond immediate physical availability;
ii. Water security should address variability and risk;
jj. Water security needs a human focus;
kk. Water security also requires meeting environmental needs;
ll. Water security requires management of competition and conflict; and
mm. Vulnerability to climate change.

Water security assessment encapsulates complex and interconnected challenges and highlights water’s centrality for achieving a larger sense of security, sustainability, development and human well-being. Many factors contribute to water security, ranging from biophysical to infrastructural, institutional, political, social and financial – many of which lie outside the water realm. Water security lies at the centre of many security areas intricately linked to water. Addressing this goal, therefore, requires interdisciplinary collaboration across sectors, communities and political borders so that the competition or potential conflicts can be resolved.

It is safe to state that investment in water security benefits human development and economic growth in the long term, with immediate visible short-term gains. Each of these themes presents challenges of varying magnitude for the Kingdom. It is imperative to understand these challenges clearly to evaluate water security at the country level.

2.3.2 Water security framework – key dimensions

The Asian Development Bank (ADB) presented the Asian Water Development Outlook (AWDO) 2013. Five key dimensions were introduced to measure the water security of countries across Asia based on the reasoning that a single focus on any of these is insufficient to guide decisions or assess outcomes in the water sector. It further suggests that the interdependent nature of different water uses is explicitly recognised by measuring national water security as an aggregate of the indicators. This interdependence means that increasing security in one dimension may affect security in another while simultaneously increasing or decreasing the indicated national water security (ADB, 2013). The five key dimensions are:

nn. Key Dimension 1 - Household Security: To provide an assessment of the extent to which household and sanitation/hygiene needs are satisfied;
oo. Key Dimension 2 – Economic Security: To provide an assessment of the productive use of water to sustain economic growth in food production, industry, and energy;
pp. Key Dimension 3 – Urban Water Security: To assess the status of urban water-related services to support vibrant, liveable cities and towns;
qq. Key Dimension 4 – To assess the status of the water-related environment of river basins using the river health index;
rr. Key Dimension 5 – Resilience to Water-Related Disasters: To measure progress toward establishing resilient communities adapting to change.

In broad terms, the key dimensions 2 and 4 are macro-level indicators requiring high-level evaluation, policy development, planning and implementation of strategic plans. While the economic security (key dimension 2) in KSA needs a comprehensive assessment of the productive use of water to sustain economic growth, the status of the water-related environment (key dimension 4) is aquifer system focused (rather than river basin focused) due to a unique water resource distribution in KSA –the result of the absence of classical river basins. The remaining three dimensions encompass an evaluation at a more operational level relying on more tangible indicators and are a means to ensure the “security of supply” at an operational level, which by itself is a foundation for broader water security at the national level.

2.4 Vulnerability to Climate Change

With only 2% of the total land as arable, KSA is particularly vulnerable to climate change due to its limited renewable water resources, low rainfall (annual average of 70.5 mm), and extremely high evaporation rates. Climate change projections consistently show that the frequency of extreme weather events will increase, requiring adaptation to new ways. The climate prediction modelling results using General Circulation Models (GCMs) indicate the average warming in KSA in 2041 to be higher than the global average, which is expected to be the highest (2.0 – 2.7 ^{o}C) during the summer months in the northwestern region. In addition, the rainfall by 2041 is expected to increase between 20 to 30% in the southwestern part of the country and to decrease by about 7 – 18 % in the rest of the country (Darfaoui and Al-Assiri, 2010).

Drought could adversely affect supply to the areas which rely heavily on renewable resources resulting in low accumulation in surface water storage and/or extremely reduced recharge of the alluvial aquifers. Shuqaiq-Khamis Mushait is almost dependent on renewable resources, with about 85% of the supply from renewable groundwater and 15% from surface water dams.

2.5 Water Security at the Country Level

2.5.1 Water resource availability

The physical availability of water in KSA is a fundamental concern. The water resources in KSA include renewable surface water collected in dams, renewable groundwater in shallow aquifers, non-renewable groundwater, desalinated water, and reclaimed water. The KSA situation regarding water resources availability is unique and is elaborated on in the following sections.

2.5.2 Renewable water resources

The renewable water resources in KSA have been estimated at 2.4 BCM/year (MoWE, 2010), concentrated in the Arabian Shield area. This does not cover the current water demand of approximately 19-20 BCM/year.

The amount of surface water is limited due to low precipitation (approximately 50 - 90 mm/year), extremely high evaporation rates (about 3500 – 4500 mm/year), and the absence of perennial rivers, streams, or lakes. More than 90% of the rain that does fall evaporates without contributing to the water resources (MOEP, 2010). Precipitation in KSA exhibits high spatial and temporal variability. Nearly all the precipitation occurs between November and April. The rest of the year is dry and hot, with average daily temperatures exceeding 38 ^{o}C in summer months and often reaching 49 ^{o}C in the country's central, western and eastern parts. Consistent with the precipitation distribution, the renewable water resources are localized in the Arabian Shield area, with better availability in the southern part and relatively less in the north.

The amount of renewable water resources (combined surface water captured in dams and groundwater in shallow aquifers) is estimated at 2.4 BCM/year. This renewable water resource's inherent spatial and temporal variability introduces a risk element from a water security perspective. The climate change impact can exacerbate due to increased variability in weather patterns. The predictions based on the climate models indicate a higher–than–average global warming and a 7-18% decrease in the average annual precipitation for 2041 (Drafaoui and Al Assiri, 2010). Therefore, KSA's renewable resources are expected to decrease significantly, putting further stress on already stressed and limited renewable water resources.

2.5.3 Non-renewable groundwater

Though huge amounts of water are stored in principal and secondary aquifers on the Arabian Shelf, not all of them are recoverable because of technical and hydrochemical constraints. Exploitable non-renewable groundwater in KSA is estimated at around 2,400 BCM and could potentially cover more than 400 years of municipal water supply. This strategic water resource in the deeper aquifer layers is protected from eventual contamination. However, this resource is being depleted by agricultural abstraction at an alarming rate of 15 BCM/year, approximately 84% of KSA's total annual water consumption. This could exhaust this strategic resource in less than 160 years if the current consumption trend is maintained. An additional risk is the deteriorating water quality due to radionuclides contamination and increasing salinity, which poses a significant threat to municipal water supply systems.

The 2010 estimates of recoverable non-renewable groundwater resources seem significant in municipal use. Still, they are limited when seen in the context of the overall water use in KSA by all sectors (agriculture, industrial and municipal etc.). The water availability is forecast to diminish in a few areas if the intense agricultural activity continues following the current practices.

2.5.4 Desalination water

The 2013 desalination capacity in KSA is around 6.91 MCM/day, almost equally distributed between the Red Sea Coast at 3.61 MCM/day and the Arabian Gulf Coast at 3.3 MCM/day. In 2013, desalination plants contributed approximately 2.52 BCM to the water stream.

Desalinated seawater, though a reliable resource in terms of availability, is produced using energy-intensive processes consuming fossil fuels (oil and natural gas). Therefore, its availability is directly linked to the availability of fossil fuels and the cost of power generation.

2.5.5 Reclaimed water

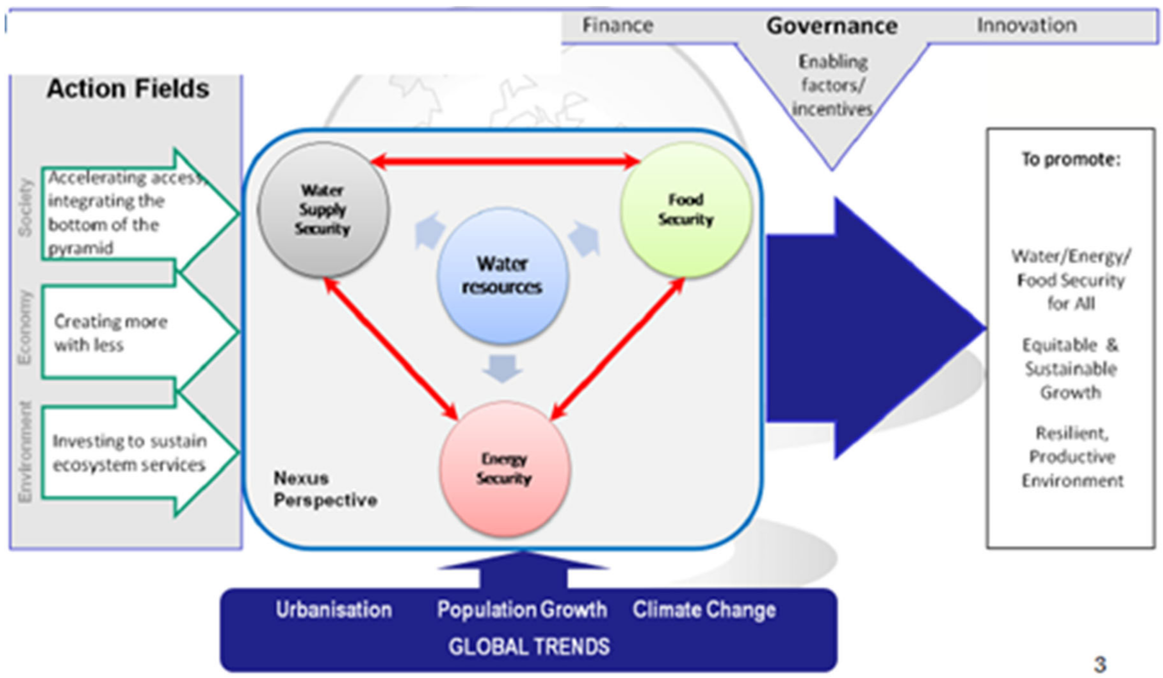
Reclaimed water is produced by treating wastewater to a level so that it can be safely reused for non-potable needs such as industrial processes and cooling, agricultural irrigation, landscaping, groundwater recharge, and ecosystem creation or restoration. The 2013 treatment capacity of all STPs in KSA is 4.77 MCM/day, based on 71 operational STPs.
The total treated wastewater volume (secondary or tertiary treatment) is estimated at 3.63 MCM/day against the estimated wastewater reuse of approximately 0.62 MCM/day (225 MCM/year). Of the thirteen regions in KSA, Riyadh, Makkah, and Eastern Region produce the bulk of treated wastewater and offer the most significant potential for reuse. In 2018, the total water used from treated water was around 18%.

Treated wastewater is, theoretically, a reliable resource with less seasonal fluctuation than surface water. It could be an alternative resource for raw water, particularly for industry, agriculture and urban landscaping; however, the current wastewater reuse is extremely low in the Kingdom (less than 20%). Moreover, current trends and policies seem to focus more on promoting wastewater reuse in industries requiring very high water quality than agriculture. Here, wastewater could substitute non-renewable groundwater with less quality than reclaimed water, as needed for alfalfa and tree corps.

2.5.6 The water – food–energy nexus

In the last few decades, it has become increasingly evident that the world’s food, water and energy resources are already experiencing stress and shortfalls, which will continue to increase in the future under many potentials. Still, likely scenarios are a combination of the growing population, increasing urbanisation rates, expanding middle class in many countries and an overall increase in resource demand. The importance of the relationships between water, energy and food (the WEF nexus) has been recognized. Many efforts have been made to highlight the increasingly complex challenges in the three domains (large quantities of water required for food and oil production, energy used in water and food production etc.).

Different researchers and organizations have developed several frameworks to define the relationships between the water energy food (WEF) elements and the character of potential responses within the WEF nexus. The current and future challenges in water, energy and food security (individually and across relationships) indicate that the WEF nexus needs to be integrated and addressed in tandem to improve our knowledge of (1) the nature of the relationships among the three elements, (2) consequences of their changes and changes in other sectors, and (3) implications for policy development and actions for addressing the three securities (Bizikova and Swanson, 2013). A few related examples of the WEF frameworks include Bonn 2011 Nexus Framework (Figure 2- 1), World Economic Forum Framework 2011 and International Institute for Sustainable Development (IISD) Water-Energy-Food Security Analysis Framework 2103 (Bizikova and Swanson, 2013).



Source: Hoff (2011), presented in IISD (2013).

Figure 2- 1 Water, energy, and food security nexus

Water, food, and energy security are ultimately about human security. We may jeopardize the region's development gains and our currently improving living conditions unless we increase water security. While the scale and complexity of this multidimensional challenge are huge, solutions are within reach. They can be achieved through well-designed policies and intelligent investments sustained by effective water governance (ADB, 2013).

KSA spends approximately 4% of its foreign currency on food imports. In 2010, KSA imported $-USD 20 billion worth of food. Import dependency is expected to remain high, particularly for strategic commodities such as cereals, which KSA has a slight comparative advantage in producing domestically. Historically, KSA has not encountered difficulties securing food imports even during high prices, such as in 2008. This secure position is expected to continue if the country maintains strong exports and food is available on international markets.

Water scarcity undermines the ability of KSA to produce food domestically. There is consensus that domestic agricultural production is economically and environmentally inefficient in KSA, except for possibly limited production of non-strategic high-value foods. This inefficiency stems from the Government's earlier policies to promote universal access to water, low pricing tariffs and the prioritization of fresh water for agriculture rather than municipal water.

To address these challenges, the Saudi government is phasing out subsidies for and procurement of domestically produced wheat and barley in the country. While the decision to stop subsidizing wheat production has been welcomed in a few quarters, concerns remain about ongoing support to other agricultural industries in which KSA lacks a comparative advantage, such as meat and dairy production. In addition, though these policy changes have led to a reduction in wheat acreage, it is believed that the farmers have replaced this crop with alfalfa – a more water-intensive crop.

In 2013, the ADF, in collaboration with MoWE, completed a comprehensive study and strategic plan for water use in agriculture. The study indicates that the agricultural sector in KSA is ranked very low concerning irrigation efficiency (average 53% for the Kingdom) and that approximately 5.65 BCM of water is wasted due to low irrigation efficiency. Water conservation measures ADF recommends will not affect food security since food production is very limited compared to imported agricultural products. The ADF study estimated the accessible supply reserves (all regions combined) at approximately 1019 BCM and forecasts that if 2010 consumption rates continue to hold, about 40% of the reserves will be inaccessible due to water quality deterioration. Reserves will start to disappear as early as 17 years in Qassim. However, they may last longer in other regions refer to figure 1-16. To mitigate these challenges, the ADF study suggests introducing measures to optimize water use, such as pricing schemes or allocation and trading of user rights, the introduction of farm water meters and policies to regulate irrigation practices.

Desalinated water production in KSA requires vast amounts of energy. The energy consumption of thermal desalination has been estimated at approximately 1.5 million barrels of oil per day (Rodriguez et al., 2012). If the historical trend in desalinated water production continues, it is expected to increase in 2025 to approximately 23 Mm^3/day (Fath et al., 2013), with a concomitant increase in energy consumption.

In KSA, water, food and energy are inextricably linked. The water sector is a large user of energy (i.e. desalinated water production), energy production (fossil fuels) uses significant amounts of water and energy (industrial use), and agricultural production (food and fodder) is a large consumer of water. A balance is needed among the three nexus elements. This will ensure the judicious use of water for agriculture to meet some level of self-sufficiency in food production, minimization of energy consumption for water production, and optimization of industrial water use in fossil fuel production and energy generation.

2.5.7 Security of municipal supply

Security of supply has traditionally been assessed using various criteria, mainly focusing on preserving quantity and quality. The list can be exhaustive but needs tailoring to suit the country's specific conditions. For KSA, the most relevant criteria could potentially include the following:

ss. Water resources diversity (desalination, different well fields, dams);
tt. Water treatment efficiency and reliability to cope with water quality fluctuation;
uu. Water transmission reliability, redundancy and operational flexibility (interconnection);
vv. Water storage and autonomy;
ww. Emergency preparedness;
xx. Level of service and tariffs; and
yy. Water regulation and management.

The security of supply is directly related to the vulnerability and the potential scale of an outage concerning events, likelihood, and consequences. The magnitude of a water outage will vary according to the event's severity and the water system's condition. The likelihood and potential impacts on basic infrastructure and water distribution operations should be assessed. Planning mitigation measures to improve water security requires that utilities identify the events to which their specific utility is vulnerable.

2.6 Assessment of Security in Water Supply

Over the past decade, the issue of water security has become a growing concern in KSA. Recent efforts and published reports have highlighted the evidence of groundwater extractions at unsustainable levels and deterioration of groundwater quality in many areas across KSA, which pose a severe threat to the availability in the near to medium term. Recognizing this, the MoWE rolled out the National Water Strategy (NWS) in 2013, which aims at the overriding goal of sustainable water use with a focus on conservation, efficiency, and security. The guiding principle outlined in the NWS related to water security is that water supplies should be assured through water management and protected in case of natural or geopolitical disasters.

2.6.1 Water resource diversity

KSA has diversified its water supply by investing heavily in desalination plants and groundwater and surface water (dam) mobilization. Through water resource diversification, KSA has been able to secure its water supply to areas which would otherwise not be able to meet their municipal water needs from one resource. However, as the extension of desalinated supply has been chiefly focused on the significant population centres, the diversification across KSA varies in different areas. The water production (m^3/day) for 2013 for each water group by water source is provided in Figure 2- 2, while Table 2- 1 presents an indicative assessment of water resource diversity.

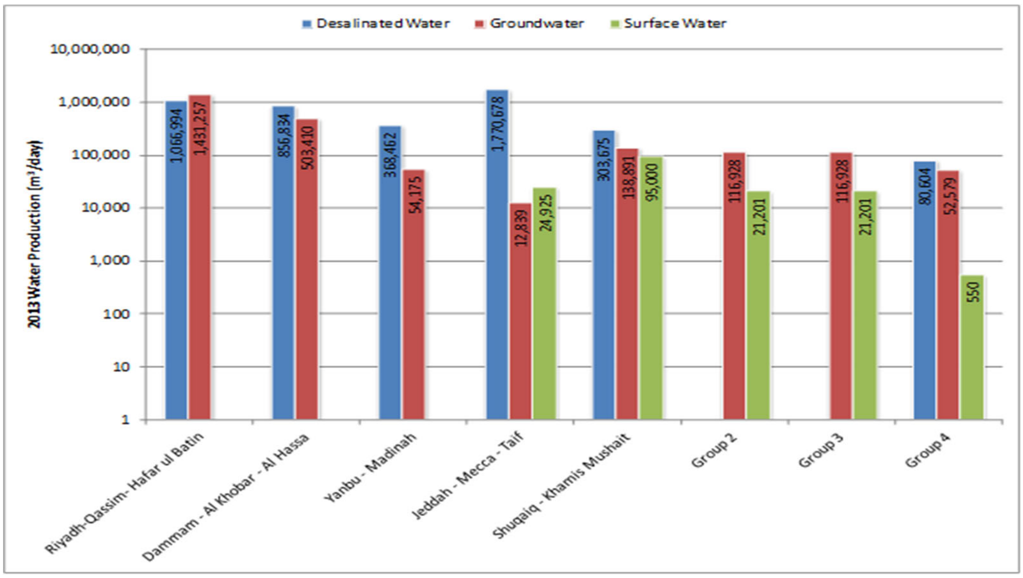


Figure 2- 2 Water production by a source per water supply group (2013)

Considered one of the main criteria of water supply security, water resource diversity (Table 2- 2) has been assessed according to the following definition extracted from international guidelines by the National Water Strategy (MoWE,2013):

Table 2- 1 Water resource diversity (2013)

Water Resource Diversity	Indication / Assessment
Water supply systems related mainly (> 70%) to one unique resource	Low
Water supply systems equipped with two water production facilities at different locations and both facilities could produce at least 30% of the demand	Medium
Water supply systems equipped with more than two water production facilities at different locations and which two facilities or more could produce at least 30% of the demand, respectively	High

It's essential to add that the guiding principal must have a balanced water supply portfolio with 30% of its annual water needs secured, corresponding to a daily requirement of 50 L/capita/day. The 30% secured water supply could also come from a separate secure source in case of damage to the existing system and/or when a utility has a strategic reserve/ storage.

Table 2- 2 Water resource diversity assessment

Region	Desalination	Groundwater	Surface water	Water Resource Diversity Level & Improvement	Actions
Riyadh-Qassim - Haffar ul Batin	43% Two desalination plants with independent water transmission: 1. Jubail 1000K m^3/day represents 50% of the total water supply 2. Ras Al Khair 1000K m^3/day represent 50% of the total water supply	57% Several well fields with 5000 to 350 K m^3/day	%0	Could be improved by connection to the Eastern region water supply system	High.
Dammam – Al Khobar – AL Hassa	63% Two desalination plants with independent water transmission: 1. Marafiq Jubail 500k m^3/ day, representing 34% of the total water supply. 2. Al Khobar (430k m^3/ day) represents 29% of the total water supply capacity.	37% Several well fields spread in Dammam and Al Hassa region	%0	Could be improved by inter-connection with Jubail and Ras Al Khair systems	High.
Yanbu-Madinah	87% Existing desalination plants: 1. Yanbu 1 (94.6K m^3/day) represent 16% of the total water supply capacity 2. Yanbu 2 (120K m^3/day) represent 20% of the total water supply capacity 3. Yanbu RO (106.9 K m^3/ day) represent 18% of the total water supply capacity 4. Movable and Albwarage (70 k m^3/ day) represent 12% of the total water supply capacity	13% 15 %for Medina city, while Badr and Yanbu governorates are mainly related to desalination (<5%)	%0	Groundwater transfer from the Tayma region could be considered as an eventual option to improve water resource diversity for the Medina water supply system, and the New desalination plant needs to cover the shortage	Medium-high
Shuqaiq	56% One desalination plant Assir region is mainly (83%) related to Shuqaiq desalination, with a maximum of 97% and 93% for, respectively, Khamis Mushait and Abha. Jazan region is related at 30% to Shuqaiq DP and 70% to renewable resources (GW and dams).	26% Several wellfields related to renewable aquifer	18% Dams related to seasonal runoff fluctuation	Increasing surface water (dam) and eventual non renewable water transfer could improve water security. Jazan region is related at 30% to Shuqaiq DP, 45% to renewable groundwater and 25% to surface water.	Medium to low

Water supply to major urban centres on both coasts and inland (Riyadh) relies heavily on desalinated water (varying between ~43% for Riyadh and ~98% for Jeddah-Mecca-Taif). The inland supply systems (Riyadh and Hafar ulBatin) receive more than 30% contribution from non-renewable groundwater. The two major supply systems on the Red Sea Coast (i.e., Yanbu-Madinah and Jeddah-Mecca-Taif) are almost reliant on desalinated water supply and thus most weak.

2.6.2 Water treatment reliability and efficiency

Delivering safe and secure water services relies on adequate water treatment capacity to provide a reliable supply of treated water equal to or exceeding the production capacity. In 2015, the installed desalination capacity in KSA was around 6.91 MCM/day, almost equally distributed between the Red Sea Coast and the Arabian Gulf Coast. In addition to hundreds of small standalone treatment plants with less than 300 m3/day supplying rural areas, there are 34 existing major groundwater treatment plants (total capacity of 1.058 MCM/day) and 5 surface water treatment plants (treatment capacity 0.287 MCM/day). KSA's combined available water treatment capacity will be around 8.26 MCM/day against a calculated water demand of 7.37 MCM/day for 2015 (MoWE 2015).

Though the combined total water treatment capacity in KSA appears to be adequate to meet the water needs country-wide, regional imbalances in the demand and supply exist due to a locally inadequate treatment capacity.

2.6.3 Desalinated water treatment

Changes in the seawater composition (chemical and biological) and quality, whether natural or anthropogenic, affect the operation of desalination plants. Several studies carried out by SWCC (Abdul Aziz et al., 2003; SWCC 2004; SWCC, 2005) have highlighted the incidents that frequently affect the desalination plants' operation on the Arabian Gulf Coast and the Red Sea Coast (planktonic bloom, influx of invasive organisms, high silt density index values, macro fouling organisms and ingress of marine algae). The Arabian Gulf Coast seems to be affected more by this marine flora and fauna. The reverse osmosis (RO) plants are considered to be more sensitive to seawater quality than the thermal plants (MSF, MED), resulting in SWCC opting for more RO plants on the Red Sea than on the Arabian Gulf Coast.

Desalination plant technologies currently used in KSA can be generally considered robust in coping with seawater quality fluctuation, though variations among different technologies exist. The thermal desalination plants (MSF, MED) are not significantly affected by the variations in the feed seawater quality; however, reverse osmosis (RO) is relatively more sensitive and requires adequate pre-treatment facilities. During the last decades, security was the main reason why KSA opted for thermal desalination in more than 80% of the desalination capacity, even though it’s more expensive than reverse osmosis in capital and operation.

2.6.4 Groundwater treatment

Groundwater and surface water treatment technologies in KSA are conventional. They vary from simple chlorination to complete treatment (coagulation, settling, filtration, microfiltration, and reverse osmosis).

As an additional security measure, most groundwater treatment plants are equipped with reverse osmosis membranes as post-treatment in case of increased water salinity or radionuclide.

2.6.5 Water transmission reliability, redundancy, and operational flexibility

Water transmission and storage are pivotal in delivering safe and secure water services. To ensure the security of supply, it is imperative that, in addition to maintaining an adequate capacity to convey the required volume of treated water, the transmission network is kept to a level that (1) services are not affected during normal, planned operating conditions, and (2) is flexible to handle partial water transmission by diverting water during emergencies. In KSA, the water transmission network used to convey water from the treatment facilities to the distribution network comprises pipelines carrying desalinated water, groundwater and mixed water (i.e., a blended mix of desalinated water and treated groundwater or surface water).

In 2014, approximately 4,589 km of trunk transmission lines carried desalinated water from the desalination plants on both Coasts to major coastal cities and Inland. At the same time, another 3,027 km of trunk lines were under construction (SWCC, 2014). Most groundwater transmission systems are limited to a few kilometres (less than 10 km), with few exceptions (Al Hunain, Al Wasia around Riyadh area), where the well fields and/or groundwater treatment plants are located more than 100 km from the supply points. There is no redundancy concerning water transmission in KSA. Though a few dual lines exist in the transmission network due to the hydraulic design for the water conveyance, no transmission pipelines have been built into the transmission system to provide redundancy in the transmission systems. In a few cases, the transmission pipelines conveying desalinated water have been interconnected with the lines from the MoWE-operated wellfield to increase the desalinated supply with the groundwater. As such, this limited interconnectivity, though providing water from an additional source, is not designed to transfer water from one transmission system to the other or from one water supply to the other.

The transmission system's reliability usually depends on the system's type. The gravity transmission systems are generally more reliable than the pumped systems. In the case of KSA, all transmission trunk lines used to convey water from desalinated plants to supplied cities have in-line pumping stations, hence vulnerable to possible electrical and mechanical failures. Depending on the topography, a few groundwater transmission lines are gravity fed and relatively more reliable. However, it is noted that these are a very small fraction of the overall transmission network.

Table 2- 3 presents the ranking assigned to each main city supply concerning water transmission. Where the transmission system solely relies on a single desalination line, a numerical score of 1 has been assigned. In the case of a dual desalination line, a numerical score of 2 has been assigned based on considering relatively less vulnerability to a total supply disruption. A numerical score of 3 has been assigned, where additional single or dual lines supplement the existing dual transmission lines. The groundwater augmentation has been further assigned an additional score of 0.5. The overall rank for the group combines the numerical average of all transmission systems and professional judgment to incorporate the considerations for transmission system length, capacity, the supplied population etc. The numerical score for each transmission system and overall group rank is presented in Table 2-3.
A description of the water transmission network is provided below. Table 2- 3 presents major water transmission trunk lines across KSA.

Table 2- 3 Water transmission reliability ranking

Main City Supply	Transmission Line	Length km	Rank
Riyadh	Jubail – Riyadh A&B	466	3
Her ul Batin	Jubail - Riyadh C	375	3
Dammam and Surrounding Cities	Ras al Khair - Riyadh	457	3
	EPTWS 1	258.03	3
	EPTWS 3	129.8	3
Hufuf	Riyadh City Feeder	132.5	3
Qassim	Riyadh - Qassim	442	2
Qassim	Buraidah City feeder	14.5	2
Hafr ul Batin	Ras Al Khair – Hafar al Batin	354.3	2
Hufuf	Khobar- Hufuf	141	1
Royal Commission	Jubail – Royal Commission	81.8	1
Madinah	Yanbu-Madinah 1	226	2
	Yanbu-Madinah 2	371.62	2
	Yanbu-Madinah 3	302	2
Jeddah	Shoaiba-Jeddah	164	2
	Shoaiba Phase 3	172	2
Mecca-Taif-Al Baha Supply System	Shoaiba-Mecca-Taif	233.8	1
	*Taif – Al Baha	227.4	1
Khamis Mushait	Shuqaiq – Khamis Mushait	216.5	1
	Shuqaiq II	829.2	1

The bulk of the water transmission network in KSA conveys desalinated water from the desalination plants located on both coasts to major coastal cities and inland. In contrast, most groundwater transmission trunk lines are limited to a few kilometres in most cases. The dual trunk lines, though extending hundreds of kilometres, exist due to the transmission network's hydraulic design and cannot be considered to provide redundancy, albeit they offer limited operational flexibility. The limited interconnectivity in a few areas between the desalinated water trunk lines and groundwater transmission lines from the MoWE-operated well fields is not designed for inter-system water transfers.

2.6.6 Water storage and autonomy

KSA currently has one of the region's lowest levels of water reserves, with less than a day’s supply held for most cities. Based on the MoWE, the storage capacity for each water group is presented in Table 2- 4. It is noted that the bulk of the storage capacity is operational storage (i.e., storage tanks forming a part of the transmission system at intermediate pumping stations). It is clear from this table that the storage capacity in most regions is lower than the Standby (Emergency) Storage of two average demand days (ADD), which is recommended by international organizations (American Water Works Association) and water agencies (Division of Environment and Health, Washington State Department).

Table 2- 4 Current water autonomy ranking

Water Supply	Production-2013 (m^3/day)	Current Water Storage Capacity (m^3)				Autonomy
		Desal. Water	Groundwater	Mixed Water	Total	(Days)
Riyadh-Qassim - Haffar ul Batin	2,498,251	0	21,100	3,557,500	3,578,600	2.01
Dammam – Al Khobar – AL Hassa	1,360,244	1,577,000	590,200	601,450	2,768,650	0.97
Yanbu-Madinah	422,637	405,000	150,300	110,000	665,300	4.33
Jeddah-Mecca-Taif	1,808,442	408,500	121,800	567,500	1,097,800	0.61
Shuqaiq	537,566	841,100	0	990,000	1,831,100	1.24
Group 1	138,129	5,600	84,000	0	89,600	0.65
Group 2[2]	138,129	301,010	0	0	301,010	2.18
Group 3[2]	133,733	30,200	10,200	10,450	50,850	0.38

There is no designated strategic reserve storage, though the actual storage can provide limited backup in case of routine disruptions (routine or emergency repairs). To enhance the reserve capacity in key population centres and create strategic reserve storage, the Saudi Government has embarked on ambitious projects. On the directions of the Saudi Government, the National Water Company (NWC) has already begun constructing eight new stainless-steel reservoirs to serve Riyadh, Mecca and Jeddah, which will hold 3.3 MCM of potable water. The storage capacity to store treated water will be enhanced to about 21.5 MCM by 2020 in the five key cities (Riyadh, Jeddah, Mecca, Medina and Taif) managed by NWC. The Saudi Government's long-term plan is to enhance the storage capacity of these five cities to around 38 million (m^3) by 2029, which is likely to improve the reserve capacity to hold 6-7 days of supply for use in emergencies or supply disruption (GWI, 2013).

There is no data available on the quantity of residential storage (i.e., underground and overhead storage tanks in individual houses, but clearly, it exists because consumers can deal with periodic loss of supply) to establish the proportion of the population and the duration of the time it can withstand supply disruptions. It is known that a significant number of individual houses and villas, especially in well-to-do neighbourhoods, have in-house water storage that can provide flexibility in emergency planning to divert water to densely populated multi-story dwellings with no storage.

2.6.7 Emergency preparedness

Currently, no strategic plans at the country level exist in KSA to cope with supply disruption due to natural disasters or hostile acts. However, this shortcoming has been recognized in the recent National Water Strategy (NWS). The two basic water security rules in the NWS are that: (i) all aquifers must be managed to retain ample strategic reserves, and (ii) each utility must have a balanced water supply portfolio, with 30% of its annual water needs secured with a minimum daily requirement of 50 L/capita/day. The NWS also requires each utility to develop and implement plans in line with the water security guiding principles of the balanced water supply portfolio and minimum daily water requirements.

In 2010 the largest floating desalination plant in the world with a production capacity of 25,000 m^3/day was launched on a barge in Yanbu to support production during high seasonal demand for potable water anywhere along the Red Sea coast. This plant provides flexibility to respond to emergencies on the Red Sea Coast. For contingency planning, a similar option could be evaluated for the Arabian Gulf coast.

2.6.8 Level of services and tariffs

KSA's water supply and sanitation services face many challenges in serving millions of people under severe water quantity and quality constraints, deteriorating water infrastructure and inadequate network management capacity. The quality of service remains below internationally acceptable standards, except in a few cities with good service, with a significant portion of the population still dependent on supply through tanker trucks. At a calculated national average of 275 L/capita/day, water consumption in KSA remains significantly above many developed countries and other countries with similar arid environments. Though no accurate figures are available, the approximate estimates indicate a national average of around 90% for water supply and 60% for sewerage. For the cities within the supply and sanitation network, the services remain below internationally accepted benchmarks concerning coverage, discontinuity of services, levels of unaccounted water (10% in some urban areas and 25-50% in most areas) and management practices.

The principal challenge in water services is that water supply, sanitation coverage, and service standards are below the expected levels in a country as developed as KSA. At the same time, the net cost to the state is high, estimated at 1% of the gross domestic product (GDP) annually (MoWE, 2013). There is a huge gap between the actual cost of supplying water and tariffs. The current water delivery cost to municipal utilities is around 8 SAR/m^3 (considering a mix of desalinated and groundwater), while the consumer tariffs range between 0.2 and 0.6 SAR/m^3.

The current level of service and tariff structure presents numerous challenges and enhances the risk of achieving water security in the following prominent ways:

zz. Reduced water supply coverage results in an inequity among the population due to a significant difference between the costs of water which is almost 10-25 times higher for non-connected people compared to what is being paid by the population connected to the public supply networks. This has the potential to cause distress and unrest among the affected population.

aaa. High Unaccounted For Water (UFW) levels in the supply system result in reduced cost recovery, increased production requirements and lower coverage.
bbb. Lack of standardization in the level of service results in inaccurate estimates resulting in significant variations in per capita water consumption planning estimates for different cities. The inability to develop sound estimates affects the overall assessment, planning and improvements in the water sector;
ccc. Lack of sanitation coverage resulting in uncontrolled sewage discharges has the associated risks of contaminating the groundwater, thus reducing its availability and potential for use as a resource and endangering public health;
ddd. Lack of sanitation coverage also results in the wastage of treated wastewater that could be reused for various uses (landscaping, irrigation of fodder crops etc.), thus reducing stress on the public supply and groundwater extraction.
eee. The current tariff structure in KSA is detrimental to water services in two ways: (1) it prevents the necessary investment in the much-needed infrastructure expansion and service improvements, and (2) it provides no incentive for behavioural changes towards recognising the importance of water conservation.

2.6.9 Water regulation and management

As amended occasionally, the legal and regulatory framework exists in the country in the form of the Water Act of 1980 and its subsequent amendments, Environmental Law of 2001 and Decision 335 (Council of Ministers, 2007). Though a few gaps in the regulatory framework were addressed by Decision 335, it is still short of being consolidated and comprehensive. While a consolidated and comprehensive regulatory framework is essential for KSA, which is onerous and time-consuming, there is an urgent need to implement the regulatory functions already established under the existing framework.

Despite the government's and other stakeholders realisation and efforts, the current water regulation and management in KSA are unsatisfactory on many fronts. There is recognition in KSA of the lack of institutional arrangement and capacity to deal with the challenges faced by the water sector related to policy and planning; resource assessment; management and monitoring; allocation, protection and conservation and provision of services. There is consensus that decentralization of management is essential to successfully manage the resources regionally by creating Water Resource Management Units (WRUMs) overseen and supported by the National Water Authority (NWA). However, the creation and functioning of such an institutional arrangement are still far from being realized. Below is a list of challenges faced by KSA from a management perspective.

fff. The lack of a comprehensive regulatory framework limits the ability of the management and regulatory agencies to develop, implement and enforce compliance. Examples include:
   – Lack of regulations on the requirements to complete baseline groundwater evaluation reports in support of the applications for groundwater extraction well licenses.
   – Lack of regulations on the volume of groundwater extraction, monitoring and reporting of groundwater levels once a well is drilled and completed after a license.
   – Lack of institutional arrangements and capacity for effective water resource planning and management.

ggg. The lack of an organized system to collect, collate, interpret, disseminate and share data on regional and national levels resulted in the following:

- It affects the capability of stakeholders to assess the current situation;
- Prevents integrated planning by different stakeholders; and
- The lack of a defined and coordinated process for water allocations in line with the existing water laws that accord the highest priority to basic human needs over agricultural and industrial uses makes it impossible to achieve any targets for reducing agricultural consumption.

hhh. The lack of effective demand management instruments (e.g., tariffs) to control the rapidly increasing water demand in the major urban centres and the lack of planning to meet the increasing industrial demand in industrial cities poses a significant risk to effectively managing the demand-supply gap.

iii. The lack of adequate government-owned local and regional real-time monitoring systems thus prevents dynamic analysis and transformation of water management objectives in real-time. Government agencies rely mostly on piecemeal studies by consultants, which become somewhat outdated by the time these are considered for planning.

Failing to act now would not only result in huge financial costs to KSA. Still, it will also seriously jeopardize its vision to achieve a sustainable, efficient, equitable and secure water future for the Kingdom. Complacency and status quo are not an option any more. KSA is at a crossroads of acting now to secure the prosperity for its future generations or continues with the current exploitation and less-than-ideal management and resource utilization practices for short-term goals, thus threatening the resource availability in the long- term.

Chapter 3

ESTIMATION OF MUNICIPAL WATER CONSUMPTION

3 ESTIMATION OF MUNICIPAL WATER CONSUMPTION

3.1 Introduction and Context

Accurate and detailed information about water consumption in urban environments is essential for developing effective Integrated Urban Water Management (IUWM) strategies and programs. Consumption data can be tracked over time to assess the effectiveness of such strategies and programs.

Emerging technologies have made it possible to estimate water demand and consumption with reasonable confidence at an appliance level. This level of detail is a key factor for understanding the main determinants of water consumption and constitutes the basis for accurate water demand forecasting models.

The main outcomes of municipal water consumption estimation are:

- A better understanding of water consumption patterns/trends and consumer behaviours,
- A clear establishment of the principal determinants, main drivers, and predictors of water consumption, and
- A depth of knowledge in water consumption and its micro-components.

Municipal water consumption is classified into two categories: residential and non-residential.

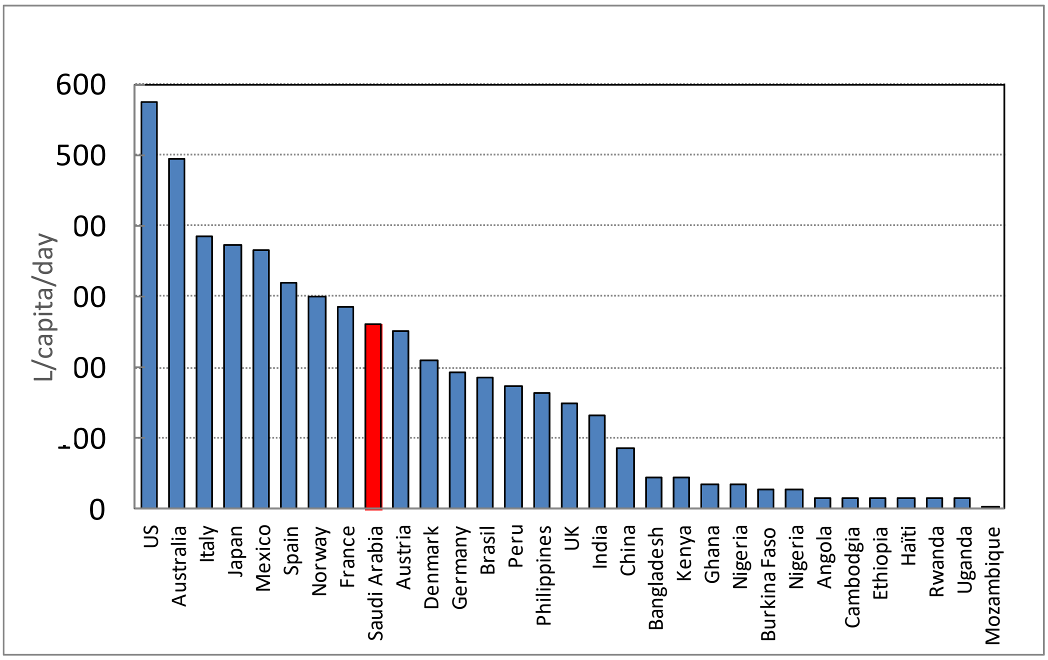
Residential water consumption: Several factors may affect residential water consumption per capita, such as household income, number and type of water-flush toilets, presence/absence of a washing machine in the home, etc. But accurate information on the overall penetration of such appliances nationally and regionally is difficult to obtain. So, the forecasting model has been developed using as few variables as possible.

Non-residential water consumption: Non-residential consumers have been divided into different subcategories based on the categories found in the available data from other Saudi Government sources (Ministry of Industry and Commerce, Ministry of Education, Ministry of Health, etc.) and on previous international experience. The main objective of this categorization has been to define homogeneous groups that share the same or similar water consumption drivers, which can be analyzed together.

3.1.1 Municipal water consumption per capita.

Figure 3 - 1 shows the average municipal water consumption per capita for different countries worldwide. The per capita municipal water consumption is calculated by dividing the water production introduced in the system by the population served.

At 275 l/capita/day, KSA's average water consumption is similar to those of northern European countries and exceeds countries like Germany (190 l/capita/day) and Denmark (210 l/capita/day). But unlike these countries with abundant water resources, KSA has very limited water resources.



Source: IWRM institute – 2010

Figure 3 - 1 Average daily municipal water consumption per capita

3.1.2 Municipal water tariffs

Figure 3 - 2 shows domestic water tariffs in different cities worldwide (Yuriev et al., 2019). At 1.35 $\$/m^3$, the water tariff in Riyadh is much lower than those in northern European countries but higher than in cities like Kabul (Afghanistan - 0.47 $\$/m^3$) and Ashgabat (Turkmenistan) and Dublin (Ireland), where a household pays nothing for water (unless consumption exceeds some specified threshold, currently 213,000 L/year in Dublin). 'Excess' consumption above this threshold is subject to a charge, currently 2.15 USD/m^3 for water supply and 2.15 USD/m^3 for wastewater collection and treatment.

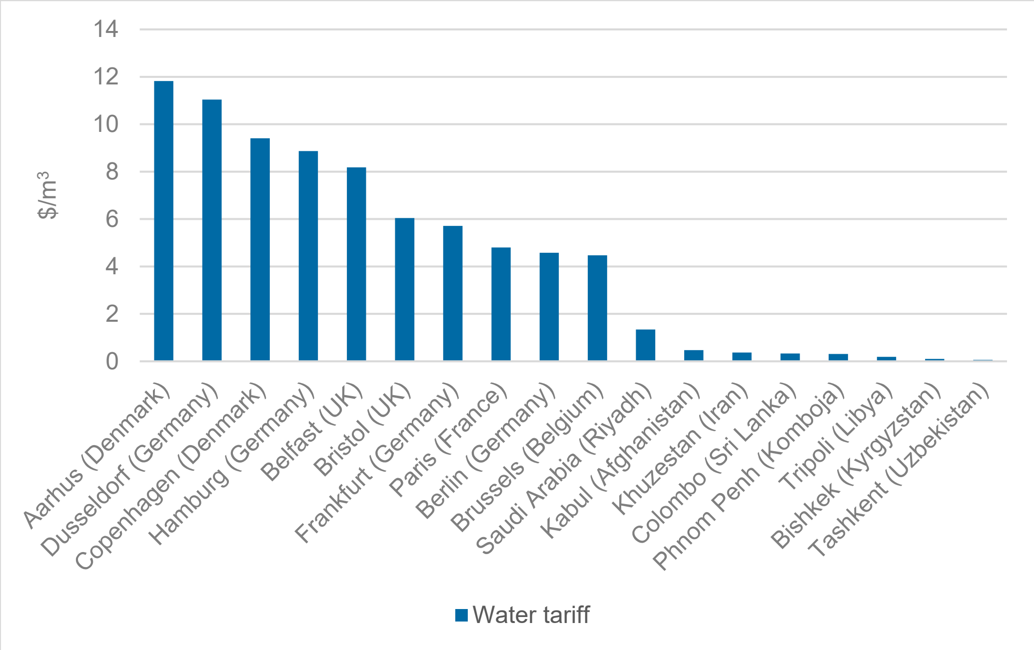


Figure 3 - 2 Domestic water tariffs in selected cities in 2015

3.2 Residential Water Consumption

To reduce water consumption and promote energy efficiency in American households, the Energy Policy Act of 1992 set a limit on the amount of water used for flushing toilets (6.1 L/flush) and the nominal flow rate and pressure of showerheads (9.5 L/min at 5.62 kg/cm^2) and faucets (8.3 l/min at 4.2 kg/cm^2). Although these figures are significantly higher than elsewhere in Europe, they are an essential benchmark for water efficiency standards.

Several detailed studies on residential water consumption have been completed globally and in KSA, and residential water consumption is already well understood. This study will focus more on estimating non-residential water consumption in KSA. However, a simplified residential water consumption model will also be presented to develop an overall figure for municipal water consumption.

Our residential water consumption model includes only those factors that can be easily obtained at a national level and/or can be derived from reliable sources. Therefore, household and irrigation/outdoor water consumption analysis is based upon water consumption per capita rather than summating end-use applications.

The next section shows a comprehensive review of a few international residential water consumption studies that have been published. These studies are used to obtain an approximate figure for the per capita water consumption and benchmark with typical values used in KSA.

3.2.1 Consumption benchmarking

Residential water consumption is moderately elastic and can change over time if the right measures are implemented and adequately communicated to consumers. Reducing residential water consumption requires a combination of pricing, regulation, and social awareness.

One water consumption efficiency measure is benchmarking water consumption against other countries with similar conditions. This provides an appropriate framework for comparison and allows water authorities to understand better the relative efficiency of their production, storage, and distribution systems and identify potential water efficiency measures to reduce water consumption. At an individual household or country level, benchmarking enables a comparison of current per capita consumption against the rest of the world.

Another effective tool is analysing how residential water consumption in different countries has evolved. For example, the USA has significantly reduced residential water consumption. Recent studies show that the average residential water consumption in the United States has decreased by 22% from 670 L/household/day in 1999 to 522 L/household/day in 2016, while the average per capita water consumption has decreased 15% from 262 L/capita/day in 1999 to 222 L/capita/day in 2016. This reduction is mainly due to the reduction in average household size from 2.77 people in 1999 to 2.65 people in 2016 and the improvement of water consumption in machines and equipment (Deoreo et al. 2016).

California's average daily residential water consumption is 768 L/capita/day, somewhat higher than the national average of 678 L/capita/day (Consol, 2010). It may be due to increased wealth, swimming pools, larger gardens, and larger house sizes. The study by Southwest Florida Water Management District (2015) indicates that the average water consumption in Florida is 507 L/capita/day compared to a national average of 541 L/capita/day (differences in national averages may be due to differences in calculating methodologies and year).

In Santa Cruz, water consumption ranges between 265 L/person/day, in a housing unit engaged with inefficient plumbing system fixtures and appliances, to 189 L/person/day, in a housing unit engaged with efficient plumbing system fixtures and appliances. Average water consumption is around 220 L/person/day (Utah Division of Water Resources, 2010).

DeOreo et al. (2011) conducted a study on 25 new houses built based on EPA's WaterSense New Home Specification Version 1.0 efficiency criteria (toilet flush volume ≤ 7.5 L/flush, shower flow rates ≤ 9.5 L/min, washing machines ≤ 114 L/load) and calculated an average consumption of 416 L/household/day. The EPA estimates residential water consumption in a 'WaterSense' new house is approx 385 L/household/day compared to 485 L/household/day in a typical house (Colorado WaterWise, 2010).

In England and Wales, the 'Code for Sustainable Homes' (CSH) sets out three levels of water efficiency: 120 L/capita/day (level 1), 105 L/capita/day (level 2), and 80 L/capita/day (level 3) (Defra, 2011). The Government has set statutory regulation (Part G of the Building Regulations) that water consumption in new dwellings should not exceed 125 L/capita/day. The legislation also limits outdoor consumption to 5 L/h/day (HM Government, 2010). Going forward, the Department for Environment Food and Rural Affairs (Defra) water strategy for England 'Future Water' sets a goal for decreasing household consumption by 13% in 2030, from 150 to 130 L/capita/day (Defra, 2008).

According to the United Nations, approximately 50-100 L/capita/day is required to sustainably maintain life and public health (UN, 2010). This is considered the minimum volume of water needed for basic hygiene and consumption.

In the UK, current residential water consumption has been estimated at 150 L/capita/day (Hunt & Rogers, 2014), but other agencies propose a target of 130 L/capita/day (Defra, 2008). In Newfoundland and Labrador, average water consumption has been estimated at 504 L/capita/day (CBCL, 2011), while, in Australia, it is estimated at 315 L/capita/day (Australian Bureau of Statistics, 2000). Based on the end-use data on 1,188 houses acquired in twelve North American sites through surveys and historical billing information, the average per capita water consumption in the US has been estimated at 262 L/capita/day (Mayer et al., 1999).

Countries similar to KSA regarding water resources scarcity, geo-climatic (desert) and socio-economic conditions are the Gulf Cooperation Council (GCC) countries, southern states of the USA, Australia and a few south Mediterranean countries. These regions can be used for comparison with water consumption in KSA. The GCC member states' water tariff and conservation policies have not been completely implemented, leading to high water consumption of over 500 L/capita/day. However, a recent demand side management (DSM) program in Dubai reduced water consumption by more than 20%, from 362 L/capita/day in

2011 to 315 L/capita/day in 2013 (Wyman 2014). Similar success has been achieved in major cities like Amman, Casablanca, Rabat and Tunis, where tariff reform and demand-side management during the last two decades have reduced water consumption to less than 150 L/capita/day (Al-Ansari et al. 2014).

3.2.2 Estimation approaches

Using linear regression methods, residential water demand can be derived from different variables such as population, household size and climate variables. Alternatively, demographic profiling can be used to estimate household water demand by factor analysis of census data to find areas with common attributes. For example, 'A Classification of Residential Neighborhoods' (ACORN) is commonly used with household demand coefficients derived from sample surveys to estimate household consumption throughout the regional population (Deoreo et al. 2016).

Water is consumed in the houses for the same fundamental activities: cooking, showering, bathing, washing, cleaning, flushing, etc. However, the water used differs from house to house (Utah Division of Water Resources, 2010). Household water consumption indicates several time and space dependent factors (Praskievicz and Chang 2009; Fox et al. 2009; Gato et al. 2007; Mayer and DeOreo 1999; Makki et al. 2011; Arbués et al. 2003). Housing unit water consumption is complicated to estimate because it is affected by; local political, economic, social, and climatological factors; population change, demand reduction, and technology; and the price elasticity of water use related to household size and income (Arbués et al. 2010).

Since the 1990s, micro-component approaches have been a subject of growing interest in research (Edwards and Martin 1995; Atkins 2007 and Butler 1993). The use of new technologies such as low-volume flow meters and recording devices have enabled total water consumption to be disaggregated by end uses, such as faucet, bathroom, shower, toilet and washing machine. These data can then be linked with knowledge of demographic profiles, climate variables, or occupancy rates to identify aggregate household water consumption. This approach has been most popular in America and Australia (Makki et al. 2011 and Mayer and DeOreo 1999) since it lets the researchers investigate water usage for different purposes in a house.

Regional and national water consumption is affected by changes in consumption per household and the number of households (Parker and Wilby, 2013). The results of a study show that water consumption per capita decreases with increasing household size but increases with household income (Edwards and Martin 1995). This complements the Russac et al. (1991) study, indicating that detached households' per capita water consumption is higher than in other household types. The results also suggest that the type of the house can be used as a proxy for the occupants' water consumption, indicating socio-economic, family size and composition of the household. A study completed in New South Wales, based on the data of the Independent Pricing and Regulatory Tribunal (IPART), shows that households occupying detached houses consume 304 m^3/year compared to 211 m^3/year for those in semi-detached houses consume, or 148 m^3/year for apartments (Patrick et al. 2005).

3.2.3 Per capita water consumption and household size

Several studies and researchers conclude that residential water consumption is affected by the number of occupants in the housing unit (Worthington and Hoffmann 2008 and Arbués et al. 2003). The strong correlation between household size and per capita water consumption is well established (Arbués et al. 2010; Hoffmann et al. 2006; Arbues et al. 2004; Schleich and Hillenbrand 2009; Smith 2010 and Arbue and Villanu 2006).

Arbués et al. 2010, developed water consumption estimates based on occupancy numbers in a housing unit in Spain. The study's outcome was that as the household size increases, the per capita water consumption decreases until it reaches five people, after which the per capita water consumption remains steady (Figure 3 - 3).

Another study conducted in Spain by Francisco et al. (2008) concluded that water consumption is related to the characteristics of the housing unit and the number of occupants - total household water consumption increases with the increasing size of a housing unit.

Smith (2010) conducted a water consumption analysis in 252 housing units. He showed that the housing unit consumes more water as the number of occupants increases until it reaches six occupants, beyond which there will be no further increase in the per capita water consumption in the housing unit (Figure 3 - 3).

Edgar (2014) also observed (based on metered water consumption of 1650 housing units) that a housing unit with one occupant consumes more water per capita than a housing unit with two or more occupants (until it reaches six). This shows that the water consumption of a housing unit benefits from economy of scale (Figure 3 - 3).

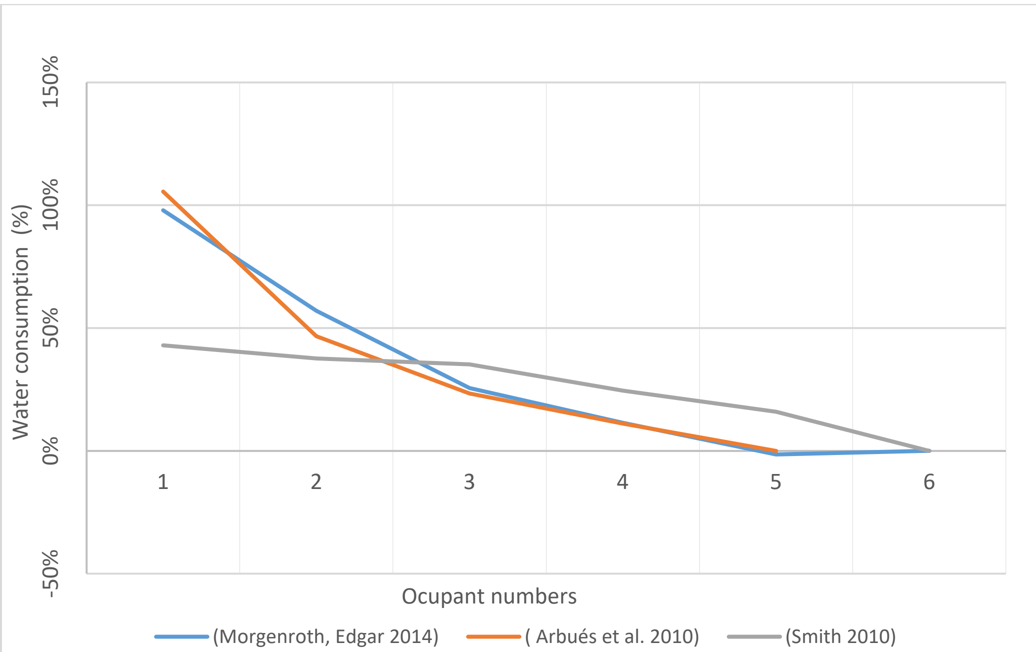


Figure 3 - 3 Per capita water consumption versus the number of occupants

3.2.4 Per capita irrigation and household size

The impact of the number of occupants on per capita water consumption in a housing unit is shown by a Box-Whisker Plot in Figure 3 - 4, based on the data collected and analyzed in several studies (Smith, 2010; Morgenroth & Edgar, 2014). The average contribution was -12%, -21%, -28%, -35% and -41% with two, three, four, five and six and more occupants, respectively, indicating that the average contribution to per capita water consumption decreased with an increase in the number of occupants in a housing unit.

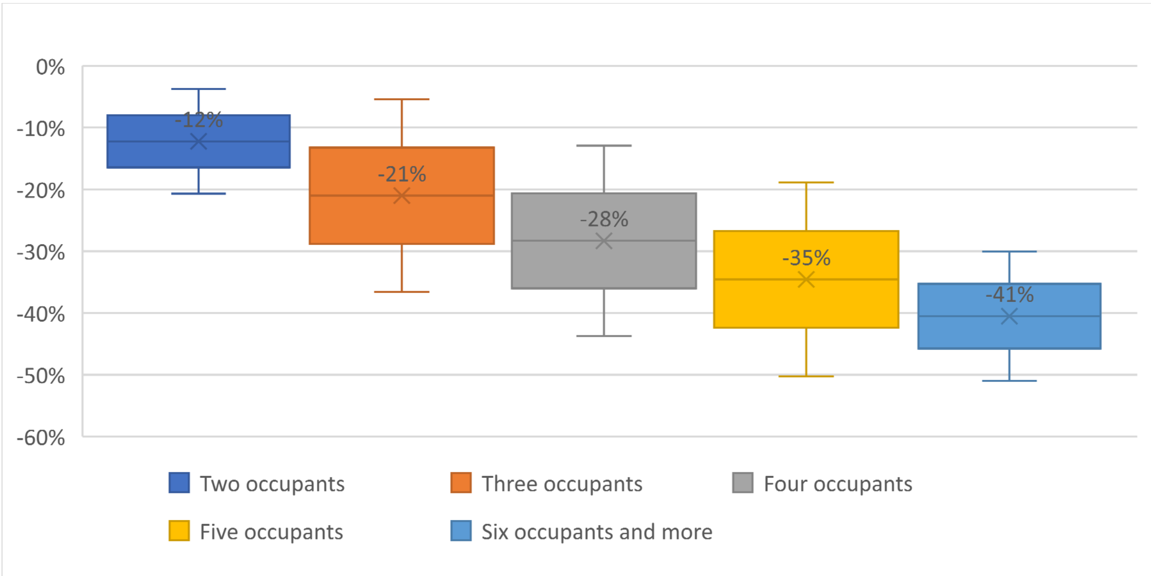


Figure 3 - 4 Percentage of per capita water consumption decrease vs occupant numbers in housing units

In Texas, the outdoor/irrigation water consumption from 2004 to 2011 was 31% of the total residential consumption (Hermitte et al., 2012). The study also indicated a strong positive relationship between outdoor/irrigation water consumption and housing unit area.

Since the per capita water consumption decreases with the number of occupants in the housing unit and irrigation water consumption was estimated at 31% of the total residential consumption (Hermitte et al., 2012), this incremental decrease can be applied to outdoor or irrigation water consumption as well, as shown in Table 3- 1.

Table 3- 1 Relation between the number of occupants and irrigation water consumption in housing units

Number of occupants in a housing unit	One person	Two people	Three people	Four people	Five people	Six or more
The average percentage of per capita water consumption decreased	100%	-12%	-21%	-28%	-35%	-41%
Irrigation water consumption expressed as a percentage of total consumption	31%	27%	22%	16%	10%	6%

The table above shows how household size changes per capita and irrigation water consumption. Where the irrigation consumption decreases in housing units as its occupant number increases until it reaches six occupants, in which water consumption gets the benefit of economies of scale in water use.

3.3 Non-Residential Water Consumption

Environmental and economic problems resulting from the excessive use of water resources have led to an increased focus on the efficient and sustainable use of water, especially drinking water (World Water Assessment Programme, 2012; United Nations, 2000). While many studies have focused on residential water demand and consumption (Brookshire et al. 2002; Arbues et al. 2003; Worthington and Hoffman 2008; Nauges and Whittington 2010), only a few of them have addressed non-residential water consumption (Renzetti 2002, 2002b; de Gispert 2004 and Worthington 2010). Very few focus on the services sector (Angulo et al. 2014).

While residential consumption can be estimated based on average per capita consumption for the different types of residential users, non-residential usage is significantly more difficult to describe. Each non-residential water consumption category has multiple drivers that affect water consumption. Farina et al. (2011) showed that per capita water consumption in non-residential buildings cannot be easily explained by a single driver that characterises water's main use. This makes capacity planning for non-residential buildings more difficult as water system operators cannot easily estimate peak demand and monthly water consumption.

Categories of non-residential consumers

We can estimate total non-residential water consumption by identifying various non-residential categories and their relative contribution to the total consumption. These categories have been selected based on available data, previous international experience, and excluding minor categories that account for only a small share of total consumption.

The following non-residential uses, as shown in Table 3- 2, have been identified as potentially significant contributors to the overall municipal water consumption. While these are the likely best proxies, the actual weight of each category must be determined based on the number of "units" and the amount of consumption associated with each "unit" consumption.

Table 3- 2 Significant categories contributing to overall municipal water consumption

Hotels	Offices	Universities
Restaurants	Wholesale and retail trade	Hospitals
Cafes	Schools	Mosques

3.3.1 Hotels water consumption

Hotels can consume large amounts of water and so can impact water distribution locally and negatively affect the neighbouring population (residential users) (Dinarès and Saurí, 2015).

Few studies describing hotel water consumption exist in the literature (Deng, 2003; Trung and Kumar, 2005; Bohdanowicz and Martinac, 2007). Published studies that define the correlation between hotel characteristics and water consumption include Gössling, 2015; Rico et al., 2009; Gössling et al., 2006; Vera, 2006; Deng and Burnett, 2002; March et al., 2004 and Kent et al., 2002. Some studies addressed factors such as water production, quality, standard, price etc. (González and León, 2001) but ignored the water use issues. Therefore, there is a need to investigate hotel water demand with a higher detail level than these studies cover.

Redlin DeRoos (1990) conducted a major study to highlight the amount of water consumption in American hotels and motels by collecting data through questionnaire results from 1600 hotels. The results indicated that: (1) the average water used was 545 L /room/day; (2) hotels with up to 75 rooms consumed around 382 L /room/day; (3) hotels with 500 or more rooms consumed around 787 L /room/day. The results of this study were also published by American Hotel and Motel Association in the book "Water Resources for Lodging Operations" (Paschke et al. 2002).

In 1991, the Los Angeles Department of Water and Power conducted a "Water Conservation Survey, Hotel Customer Category" survey. In this survey, data were collected from Hilton Hotel Los Angeles and indicated an average daily water consumption of 912 l/room/day.

It has been reported by Stipanuk (1996) in a study on environmental issues and the United States hotel industry that in the late 1920s, the average water consumption was 1143 L/room/day for hotels with 20 – 500 rooms; by 1940, the water consumption had increased to 1514 l/room/day for hotels with 47 - 2710 rooms. The study also reported that in the 1990s, the average water consumption for luxury and first-class hotel buildings was as much as 658 L /room/day.

In 1998, Greater Vancouver Regional District managed the study "Study of Water Consumption and Conservation Potential in Greater Vancouver's Hotel Industry". In this study, the water consumption was calculated based on an end-use survey for selected hotels and from billing data. The result showed that the water usage across rooms with different categories ranged between 371 L/room/day to 1601 L/room/day (Greater Vancouver Regional District, 1998).

In 2002, Seattle Public Utilities Commission (SPUC) completed a pilot study to build an inventory of baseline data on water usage in selected hotels in Seattle, which could be used for any further analysis. The data comprised published data (collected & assembled through a literature review) and data collected through a survey of selected hotels. They found that the daily water consumption in both these data sets was 378 to 1514 L/room/day (SPUC 2002). However, it was also found that the hotels with higher ratings (more luxurious) had higher water consumption per guestroom (Paschke et al., 2002). This compares to a range of 100 –

2000 L /room/day (Gössling, 2002; European Environment Agency, 2003; De Stefano, 2004; Gössling et al., 2012a).

In 2002, another study was conducted to examine water consumption in 17 hotels in Hong Kong by Shiming. Water Use Index (WUI), defined as the total annual water consumption divided by the total floor area of a hotel expressed in m^3/m^2, was used as a benchmark to assess the water use performance of each hotel. In addition, the author also analyzed the operational factors influencing water usage, such as laundry load, number of guests, and number of food orders made. After that, water billing information and hotel operations factors were collected to assess water usage performance. This study showed a wide range of WUIs between 2.1 and 7.7 m^3/m^2, with an average value of 4.5 m^3/m^2 (Shiming D., 2002). These results indicated that water consumption and use differ significantly from one hotel to another. The highest WUI average was 5.1 m^3/m^2 for the five-star hotels, while the lowest was 3.3 m^3/m^2 for the three-star and four-star hotels. WUI indicated a median of 4.1 m^3/m^2. These findings support the concept that more luxurious hotels with higher star ratings generally have a higher water consumption per room than lower-starred hotels.

In 2002, a comprehensive study was carried out to establish baseline water usage in hotels and explore the possibility of implementing water conservation in hotel facilities. The data sources included public and private organizations in addition to published literature. This study showed that the average water consumption in hotels, regardless of class, ranged between 379 to 1514 l/room/day, with an average of 946 l/room/day (Paschke et al.2002).

According to Bohdanowicz and Martinac (2007), the key factors impacting water consumption in hotel facilities are the hotel's star rating, total hotel floor area, number of guestrooms per night occupied and the number of food covers serviced. On the other hand, Erdogan and Baris (2007) and Gautam et al. (2016) attempted to estimate hotel water consumption based on hotel standards, size, level of service, outdoor area, and weather conditions.

In 2012, a water conservation study was conducted at two Malaysian resorts to implement water conservation practices. The study obtained a baseline of the water consumption framework, which audited, categorized, and measured all water use in those resorts. The information collected included: the number of rooms sold, occupancy rates, and guests per room. Additionally, a survey was conducted to find out the number of guests, number of rooms, average duration of stay, number of swimming pools, kitchens, laundry services and outdoor facilities at each hotel. The results indicated that the average daily water consumption was about 500 l/room/day (Tang, 2012), which is rated poor according to International Tourism Partnership (ITP) rating indicator (Tang, 2012), as shown in Table 3- 3.

Table 3- 3 Hotels water consumption efficiency benchmarking

Number of rooms	Water use rating (L/room/day)			
	Above normal	Normal	Low	Very low
<50	<440	116 – 510	510 – 585	>585
50 – 150	<585	585 – 675	675 – 810	>810
>150	<585	670 - 860	860 – 985	>985
Source: International Hotel Environment Initiative				

In 2016, Gautam and his colleagues developed a water consumption benchmark for five-star hotels using Delphi techniques. They collected data through a questionnaire answered by experts from sponsors, researchers, and decision-makers. The analysis indicated that guests typically consume 400 l/room/day, considered a benchmark for freshwater consumption in five-star hotels (Gautam et al., 2016).

In summary, per room water consumption in hotels varies according to the hotel star rating. So data from different hotels cannot be compared directly against each other unless the hotels have the same star rating. But even if this is the case, the ‘non-room’ facilities (e.g. swimming pool, gardens, restaurant, etc.) in the hotels may vary, likely affecting water consumption.

3.3.1.1 Hotel water consumption micro-components analysis

Understanding the micro-components of hotel water consumption can provide a better thought of the share of each micro-component in the overall consumption.

According to a study conducted in Germany by Styles et al. (2013), water consumption in hotels was distributed as follows: 34% in guestrooms; 22% in the kitchens; 17% in the laundry; 5% in cooling and heating; 2% by the swimming pool; and 20% on other activities which include unaccounted and unintentional use.

In Australia, Smith et al. (2009) surveyed a representative sample of Australian hotels and found that water consumption was distributed as follows: 42% of water was consumed in the guestrooms; 16% in the kitchens; 10% for air conditioning (cooling tower); 3% for irrigation (gardens, etc.), 2% in the swimming pools; and 12% on other uses which include unaccounted and unintentional use.

In the USA, Albrecht et al. (2009) showed that according to the information collected in their study, the water consumption breakdown in a hotel is as follows: approximately 30% for guestrooms, 25% for kitchens, 15% for cooling and heating; 20% for laundry; and 10% for landscaping and irrigation.

Similar results were obtained in another study conducted in Portugal (Tuppen, 2013), where 34% of water consumption was associated with guestrooms; 14% was consumed in the kitchens; 11% in the laundry; 17% for cooling and heating; 5% in the swimming pools; 1% for irrigation; and 18% on other uses which include unaccounted and unintentional use.

Based on data from these different studies (Styles et al., 2013; Smith et al., 2009; Albrecht et al., 2009; Environmental Protection Agency 2016; Greater Vancouver Regional District, 1998;

Meade and Gonzalez-Morel 2011 and Tuppen, H. 2013), the contribution of each water consumption micro-component concerning total hotel water consumption is presented as a Box-Whisker Plot, in
Figure 3 - 5. As shown in the Figure, the average contribution for guest rooms was 34%, 8% for irrigation, 15% for cooling and heating, 17% for kitchen, 15% for other, which include unaccounted and unintentional use, 14% for laundry and 3% for the swimming pool.

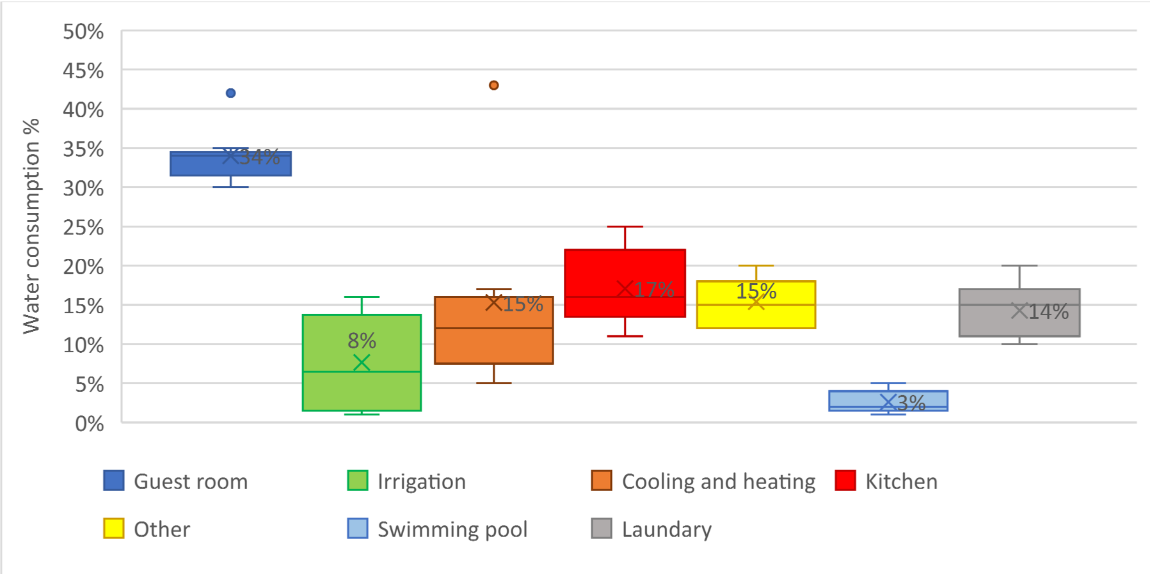


Figure 3 - 5 Analysis of water consumption micro-components in hotels by use

The following analyses are based on hotel data, but they may also be extrapolated to other non-residential categories, such as restaurants, cafes, schools, universities etc. This is because some water consumption uses are not associated with hotels only. Conversely, micro-component data (for example, in showers or by faucets) from other categories may be used to estimate the contribution of hotel showers or faucets to total hotel water consumption.

3.3.1.1.1 Guest room water consumption and analysis

Total water consumption differs from hotel to hotel, but guest rooms are often the major component of hotel water use (Sydney Water 2001; Tang 2012; Bohdanowicz and Martinac 2007; Deng and Burnett 2002; Trung and Kumar 2005). A guest room typically has a bathroom which consists of a bathtub with handle mixed faucet, thermostat mixed shower, washbasin with washbasin mixer and a flush toilet tank (Bohdanowicz and Martinac, 2007a). According to hotel water conservation studies, the highest water consumption in guest rooms is associated with toilets and showers (Paschke et al., 2002). Therefore, water consumption in guest rooms (mainly showers, faucets and toilets) needs to be analyzed to quantify the volumes of water used in guest rooms and to identify a unitary water consumption. It is to be noted that the hotel guest room analysis is not limited to the hotel sector only and can be used for other categories where appropriate.

In 2008, World Travel Market (WTM) estimated that the guest room water consumption percentage was 33% - 35% of total hotel water consumption (Dinarès and Saurí, 2015). This compares to the range of 44% - 45% in the study by Tang (2012) but only to 20% in the study by Paschke et al. (2002) and Shiming (2002). This discrepancy requires a more detailed investigation and analysis. For example, Paschke et al. (2002) estimated the average water consumption in a guest room at 164 (L/room/day), while Tang (2012) arrived at a much lower figure of 80 (L/room/day).

According to Murakawa et al. (2007), the average daily water consumption in a guest room is 673 - 729 L/room/day, similar to the 682 - 673 L/room/day range seen in two Malaysian resorts (Tang, 2012). However, these figures are much higher than the 291 L/room/day estimated by Shiming.D, (2002) and 182 L/room/day estimated by Paschke et al. (2002).

Water consumption in guest rooms must be analyzed to quantify water volumes and identify unitary water consumption. Therefore, guest rooms' water consumption can be analyzed by determining their percentage and contribution to total hotel water consumption to determine the water consumption per room. It is to be noted that the guest room analysis is not limited to the hotel sector only and can be used for other calculations based on similarities.

The guest room water consumption concerning total hotel water consumption is shown in Figure 3 - 6, which is based on the data from several studies (Tang, 2012; Shiming.D, 2002; Paschke et al., 2002; Styles et al., 2013; Smith et al., 2009; DPPEA 2009; Environmental Protection Agency 2016; Greater Vancouver Regional District, 1998 and Meade and Gonzalez-Morel 2011). From all the studies, the resulting average contribution is 35%. The remaining statistics are shown in the figure below.

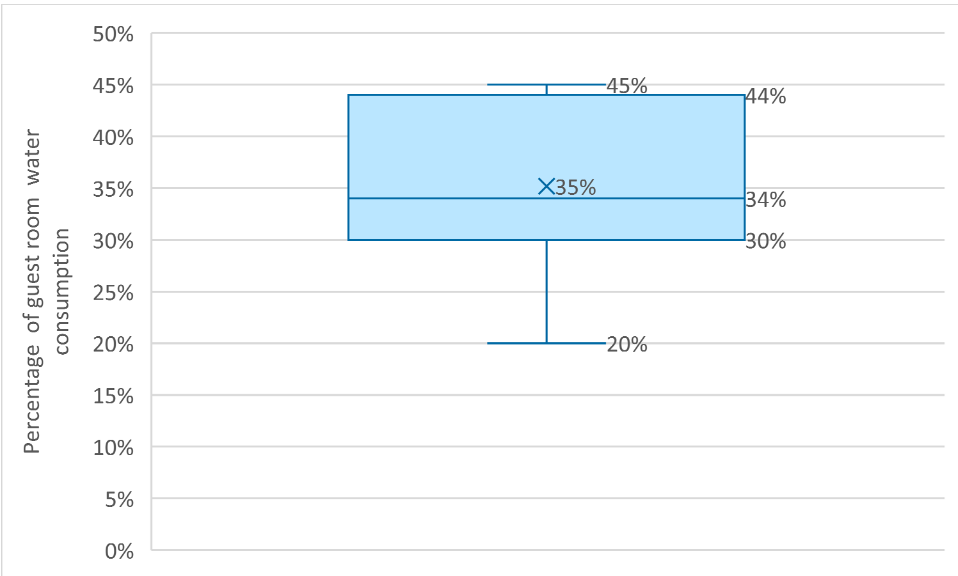


Figure 3 - 6 Guest room expressed as a percentage of total hotel water consumption

Besides, the average guest room water consumption per hotel (in L/d) is shown in Figure 3 - 7, which presents data collected and analyzed from several studies (Tang, 2012; Paschke et al., 2002). From all the studies, the resulting average water consumed is 130,821 L/day. The remaining statistics are shown in the figure below.

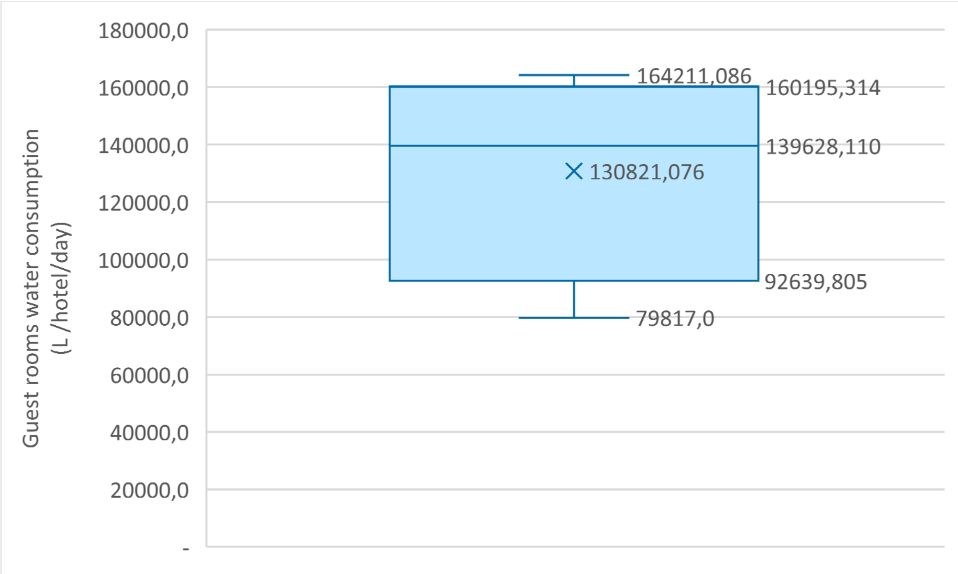


Figure 3 - 7 Daily water consumption in guest rooms per hotel

We can calculate the average water consumption per guest room, considering the number of rooms in the hotel, as shown in Figure 3 - 8, which presents data collected and analyzed from several studies (Tang, 2012; Shiming.D, 2002; Greater Vancouver Regional District, 1998). From all the studies, the resulting average consumption in the guest rooms is 457 L/room/day. The remaining statistics are shown in the figure below.

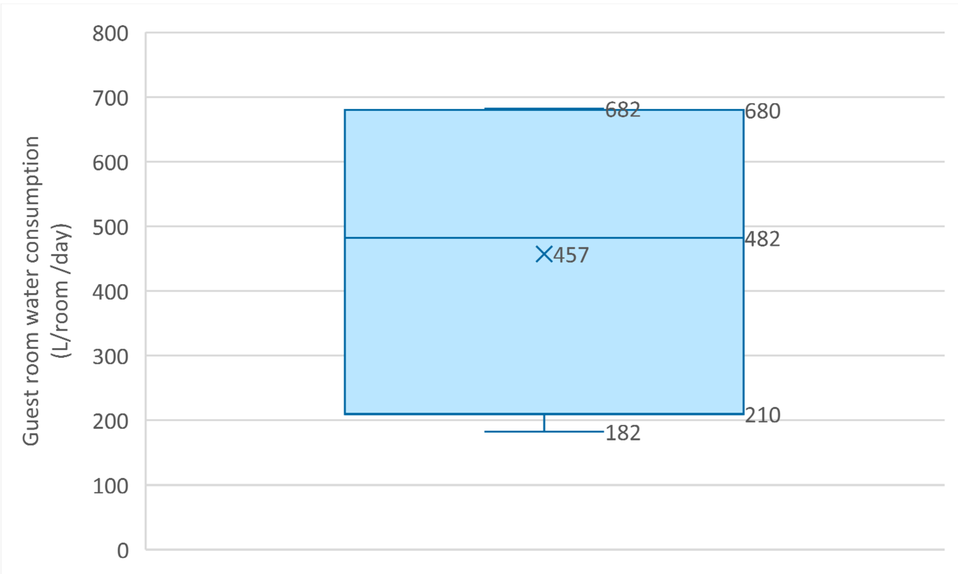


Figure 3 - 8 Average water consumption per guest room

These studies show that water consumption per guest room varies widely and that we need to disaggregate the data further to understand better what drives consumption.

- The major water-consuming activities in guest rooms are showering and bathing, which account for 50% and 42%, respectively (Tang, 2012).
- Average water consumption in guest rooms is reduced by 10-15% if high-efficiency water equipment is installed (Environmental Protection Agency, 2016).

Water consumption in the guest rooms can be further broken down by activity - shower, faucet and toilet use. Each of these items is detailed below.

3.3.1.1.1.1 Shower

DeOreo and Mayer (2014) categorized showers into two groups: over-the-bath combination showers and dedicated stall showers.

The same faucets control flow to the shower and bathtub in a tub or shower combo. These have a high initial flow (to the bath) when the faucets are opened, and the temperature is adjusted. Then when the valve is closed, the flow is diverted to the shower head. The valve is kept closed by flow to the shower head until it is reduced, and the valve returns to its starting position. The flow rate for this type of shower ranges from 18.9 l/min to 7.6 l/min during the shower duration.

In a stall shower, flow occurs directly through the showerhead. It is subsequently limited by the showerhead's flow rate, which depends on the flow rating of the showerhead and the operating water pressure. Most hotels are equipped with high-flow shower heads. It is uncommon to find shower heads that use less than 7.6 l/min (Meade and Gonzalez-Morel, 2011).

Ordinary showerheads typically consume 19 -27 l/min (Schultz Communications, Albuquerque,1999). This range is broader than that reported by Albrecht et al. (2009), where most classic shower heads consumed 11.4 - 26.5 l/min at a water pressure of 5.6 kg/cm^2 m (Albrecht et al., 2009). In 1994, the National Energy Policy Act of 1992 set a maximum flow rate of 9.5 l/min for shower heads in all new buildings (Pacific Institute, 2006).

Meade and Gonzalez-Morel, (2011) conducted a study in Jamaica. Based on 20 audits of hotels and resorts, their analysis showed that shower consumption depends on water pressure. Therefore, the amount of water used in a shower can change from 4 to 38 l/min based on water pressure and the type and condition of the shower head.

According to “Residential End Uses of Water Study”, the average number of showers per person per day in the US was in the range of 0.69 to 0.66 with a shower duration of 7.8 min/shower and average flow rates in the range of 2.1 to 2.2 l/min (DeOreo and Mayer, 2014). This translates to a volumetric consumption of 57-68l/day (DeOreo and Mayer, 2014). Another study estimated the average shower heads flow rate in the range of 26-38 l/min and an average shower duration of 12-15 min/shower (Wastewatergardens, 2000).

Based on a study covering 22 municipalities in US and Canada, an average shower consumed 57 litres of water (DeOreo and Mayer, 2014). Still, most other studies use figures around 65 l/shower (Mayer et al. 1999).

To estimate the shower water consumption per person, the shower flow rate and duration must be determined.

Data collected and analyzed from several studies (DeOreo and Mayer, 2014; Meade and Gonzalez-Morel, 2011; Albrecht et al., 2009; Paschke et al., 2002; Schultz and Albuquerque, 1999; Pacific Institute, 2006; Brown and Caldwell Consultants, 1991 and Hernaiz 2017) is shown in Figure 3 - 9. From all the studies, the resulting average flow rate is 9.4 l/min. The remaining statistics are shown in the figure below.

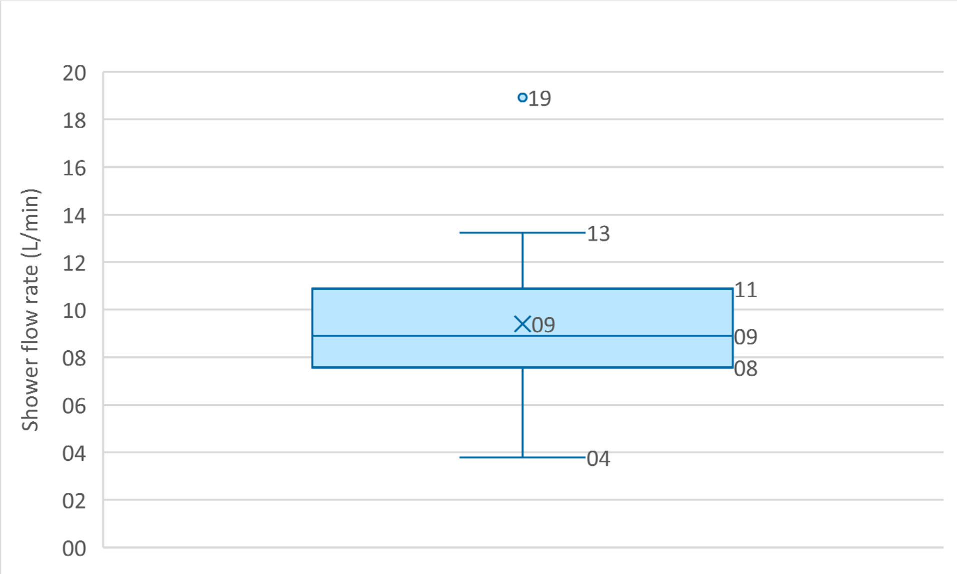


Figure 3 - 9 Shower flow rates (L/min) averaged from multiple sources

The distribution of the shower duration is shown in Figure 3 - 10, which presents the data collected and analyzed from several studies (DeOreo and Mayer, 2014; Paschke et al., 2002). From all the studies, the resulting average distribution is 11.4 minutes. The remaining statistics are shown in the figure below.

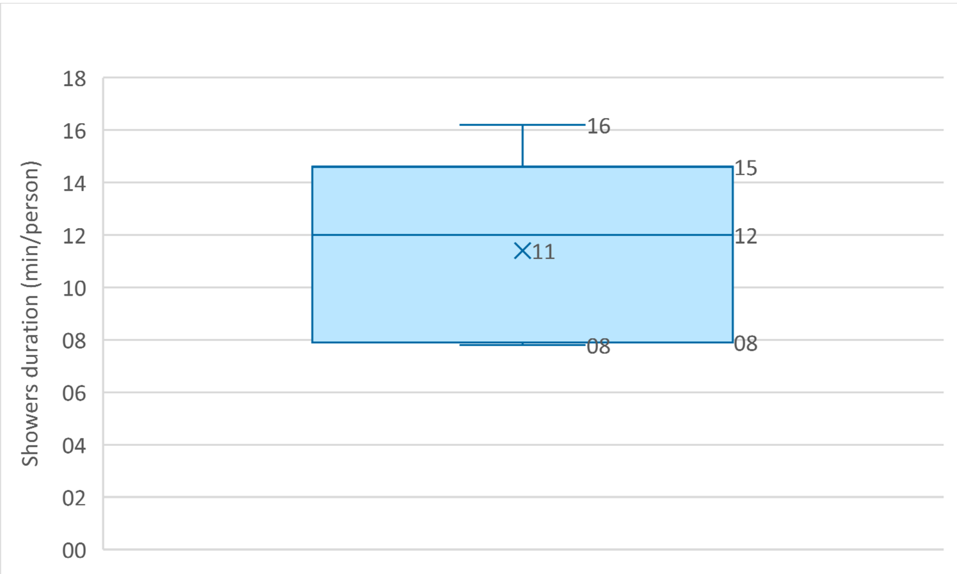


Figure 3 - 10 Shower duration (minutes) averaged from multiple sources

Therefore, an average daily shower water consumption of 9.4 L/min (Figure 3 - 9) and an average shower duration of 11.4 minutes (Figure 3 - 10) means a typical shower consumes

107 litres. These values are close to the estimated average daily per capita shower water consumption of 114 l/person/day (Paschke et al. 2002).

3.3.1.1.1.2 Faucet

In the United States, the maximum faucet flow rates have been regulated by national plumbing standards since 1994 and should not exceed 9.5 l/min at a water pressure of 5.6 kg/cm² (Pacific Institute, 2006 and EPAct 1992). Before 1994, faucet flow rates ranged from 10.4 to 26.5 l/min (Gleick et al., 2003; Portland Water Bureau customers, 1994).

In 1999, the Water Research Foundation published its Residential Water End Use Study, which indicated that the average daily faucet water consumption was 100-102 L/day/person. This was based on 28,015 recorded days in residential houses, where faucet use was 41 L/capita/day with an average of 8.1 min/capita/day (Mayer et al. 1999).

Seattle Public Utilities Commission (SPUC) observed that the average faucet use in the hotels was estimated at 3 min/day by each guest resulting in the faucet water consumption of 34 L/guest/day (SPUC 2002). In another study, a washbasin faucet is estimated to operate around 1 min/day at 9.5 L/min and account for about 38 L/room/day, or 2800 L/day (Paschke et al. 2002).

Las Vegas hotels' combination faucet flow rate (old and new faucets) was estimated to be 11.4 l/min (Pacific Institute, 2006). In Jamaica hotels, the estimation of faucets flow rate, in the range of 1.9 - 38 l/min, depends on water pressure, faucet model, and the type and condition of the aerator installed on the faucet (Meade and Gonzalez-Morel, 2011). Faucet aerators are designed to mix air with water and are generally available at 1.9, 5.5, 7.5, 8.3, and 9.5 L/min models (Meade and Gonzalez-Morel, 2011).

A study completed in 2014 indicates that each faucet type has different types of water signature based on the flow rate. In a bathroom or kitchen, the faucet's higher flow rates are estimated to be less than 9.5 L/min and the lower flow rates at a maximum rate of 5.3 L/min. Whenever the faucet was used, the volume of water consumption did not exceed 38 litres of water, and the average flow rate was 1.9 L/min with an average duration of 30 seconds. (DeOreo and Mayer, 2014).

The flow rate and duration must be determined to estimate the faucet water consumption.

Data collected and analyzed from several studies (DeOreo and Mayer, 2014; Energy Policy Act,1992; Gleick et al., 2003; Pacific Institute, 2006; Portland Water Bureau customers, 1994; Hernáiz 2017; Paschke et al., 2002; Meade and Gonzalez-Morel 2011) is shown in Figure 3 - 11. The resulting average facet flow rate is 9.05 L/min from all the studies. The remaining statistics are shown in the figure below.

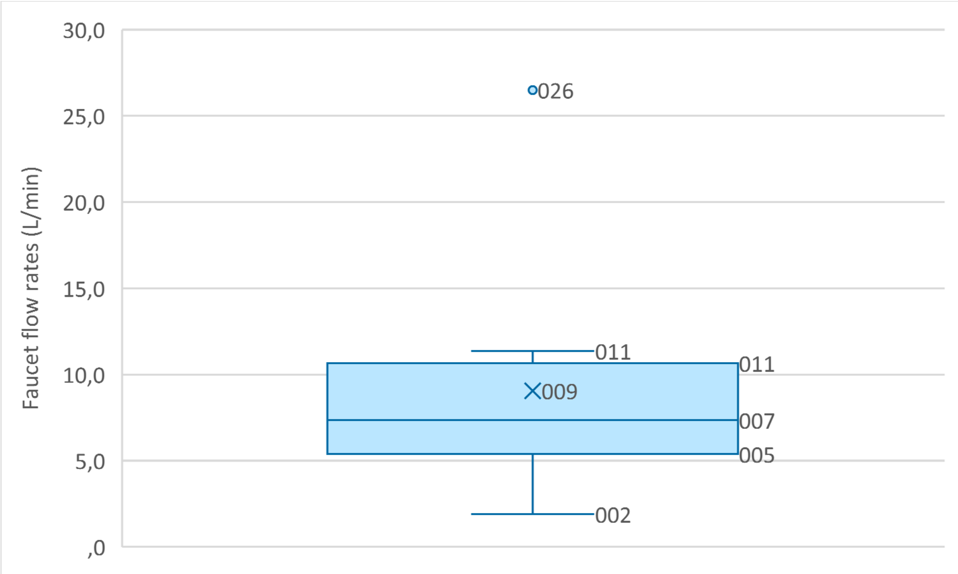


Figure 3 - 11 Faucet flow rates (L/min) averaged from multiple sources

The distribution of faucets duration is shown in Figure 3 - 12, which presents the data collected and analyzed from several studies (DeOreo and Mayer, 2014; Energy Policy Act,1992; Seattle Public Utilities Commission,2002; Paschke et al., 2002). From all the studies, the resulting average distribution is 3.15 minutes. The remaining statistics are shown in the figure below.

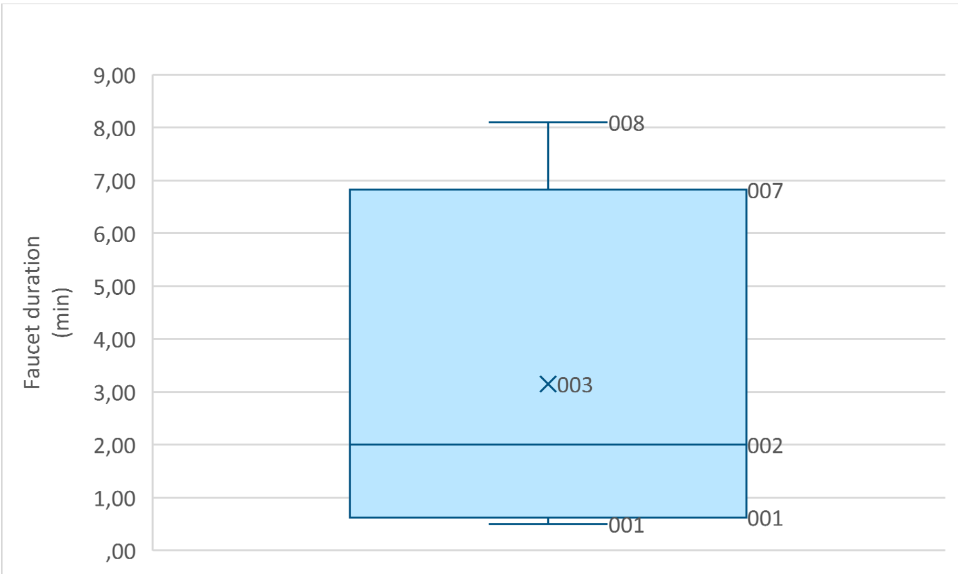


Figure 3 - 12 Faucet open duration (minutes) averaged from multiple sources

Therefore, an average daily facet water consumption of 9.05 L/min (Figure 3 - 10) and an average faucet open duration of 5.13 min/person (Figure 3 - 11) means that typical facet water consumes 29 L/person/day. This value is smaller than the estimated average daily water faucets consumption of 34 L/person/day (Seattle Public Utilities Commission, 2002).

3.3.1.1.1.3 Toilet

To quantify the water consumption used by flushing toilets and urinals, Americans are estimated to use about 18.17 billion litres of water daily (Albrecht et al. 2009).

There are three standard models of toilets: gravity flush, flush valve, and pressurized tank type. Recently, dual-flush toilets have appeared in the market. (Albrecht et al. 2009).

In 1977 and earlier, gravity toilets used in the range of 19-26.5 L/flush (New Mexico Office of the State Engineer, 1999; Albrecht et al., 2009) and flush valve toilets used in the range of 17 to 19 L/flush (Albrecht et al. 2009). From 1977 to 1990, several improvements were made to these models that reduced their water consumption to 11.4 L/flush (Albrecht et al. 2009) and 13.3 L/flush (WRATT, 1998). In 1990, the gravity tank and flush valve models' water consumption was further reduced to 6.1 L/flush (WRATT, 1998 and New Mexico Office of the State Engineer, 1999). After that, several improvements were made in toilet water consumption over time until the high-efficiency toilets appeared in the middle of 2000, consuming less than 4.9 L/flush (Albrecht et al. 2009).

In the United States, from 1992 and before, many states and municipalities interested in water conservation promulgated unique standards that made it difficult for manufacturers and distributors to meet. The Energy Policy Act developed water efficiency plumbing standards for certain plumbing devices and developed a set of unified national standards. In 1994, US federal standards effectively required a maximum water consumption for toilets of 6.1 L/flush and 3.8 L/flush for urinals (Albrecht et al. 2009).

In 1992, the National Energy Policy Act (NEPAct) required a standard toilet water consumption of 6.1 L/flush (DeOreo and Mayer, 2014). Efficient toilet models have recently reduced consumption to 4.8 -4.2 L/flush (DeOreo and Mayer, 2014).

Based on 1188 studied homes, 101 (8.5%) had ultra-low flow (ULF) toilets with an average water consumption per flush of 7.6 litres or less. The average number of flushes was 5.04 flushes/person/day, and the average water consumption was 36 L/person/day for toilets only. Another 311 homes (26.2%) used a mixture of ULF and non-ULF toilets which used 66.6 L/person/day with an average number of flushes used as 5.39 flush/person/day. The 776 studied homes were found to have “non-ULF” toilets with an average number of flushes used of 4.92 flush/person/day and average water consumption of 76.1 L/person/day (Mayer et al. 1999).

According to one hotel water conservation study, the toilets in their north and south tower guest rooms consumed about 13.3 L/flush, which would be replaced with 6.1 L/flush and estimated use to be 7 flushes/room/day (Paschke et al., 2002).

In Las Vegas, it was estimated that toilet water consumption in its hotels and resorts was 13.3 L/flush with an average of 4 flushes/guest/day and 2.6 flushes/room/day for cleaning (Pacific Institute, 2006). Given that the average number of occupancies can be estimated to be 2.1 guests/room, the number of toilet flushes equals 3.1 flushes/guest/day (GLS Research 2006).

In Jamaican hotels, the old toilet model, consuming 19-26.5 L/flush, was replaced with more conservative models, which consume 6.1 L/flush (Meade and Gonzalez-Morel 2011).

In residential houses, it is estimated that the average number of flushes per person and day, based on 762 recorded days, was 5 flushes/person/day. The average water consumption per flush was 9.8 litres. Based on 1187 recorded days, it was 4.6 flushes/person/day, and the average flush consumption was 13.8 litres (DeOreo and Mayer, 2014). Based on the most frequently cited data from the studies, the average number of flushes per person per day was 5.05 flushes/person/day, and the toilet water consumption was 70 L/person/day (Mayer et al. 1999).

The typical urinals, which have a flushometer valve or water tanks for washdown and trough urinals, consume 7.6-11.4 L/flush for older models (Albrecht et al. 2009).

The toilet water consumption in guest rooms was analyzed through different approaches to determine the amount of water consumption used and frequency of use, which enables the development of uniform units, such as toilet water consumption per person. Notably, toilet analyses are not limited to the hotel sector unless otherwise specified.

To estimate the toilet water consumption per person, the number of flushes must be determined.

Data collected and analyzed from several studies (Albrecht et al., 2009; DeOreo and Mayer, 2014; Mayer et al., 1999; Paschke et al., 2002; WRATT, 1998; New Mexico Office of the State Engineer, 1999; Pacific Institute, 2006) is shown in Figure 3 - 13, From all the studies, the resulting average toilet water consumption is 12.12 L/flush. The remaining statistics are shown in the figure below.

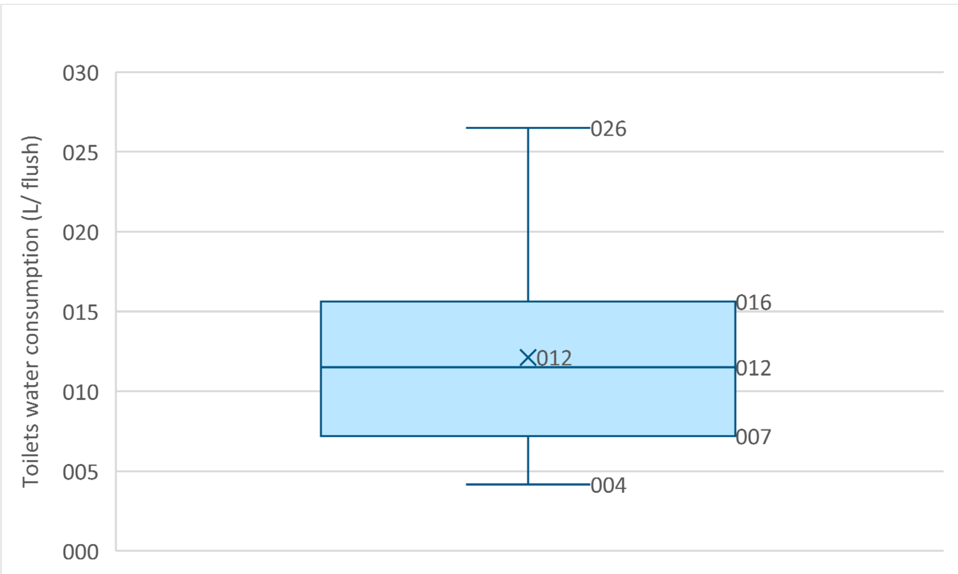


Figure 3 - 13 Toilet water consumption averaged from multiple sources

The distribution of the daily number of flushes per person is shown in Figure 3 - 14, which presents the data collected and analyzed from several studies (DeOreo and Mayer, 2014;

Paschke et al., 2002; Pacific Institute, 2006). From all the studies, the resulting average distribution is 5 flushes. The remaining statistics are shown in the figure below.

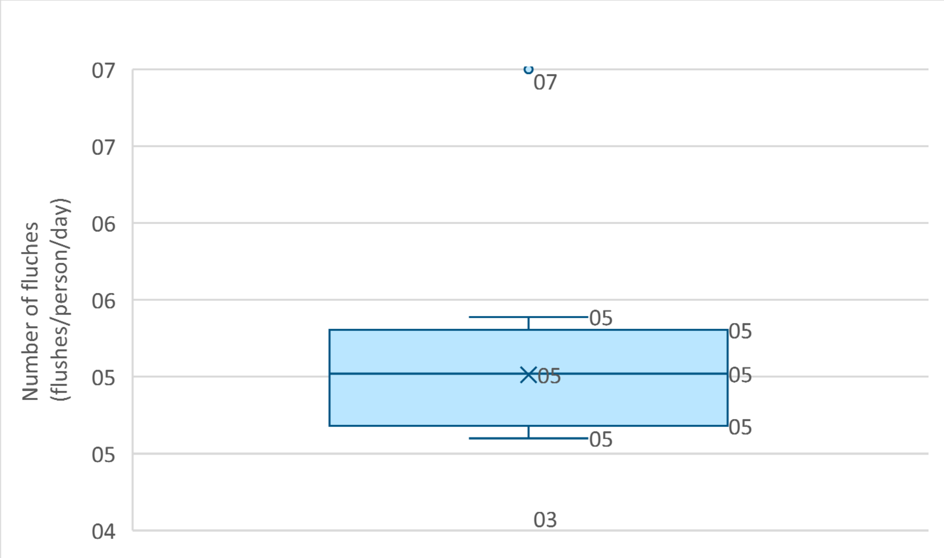


Figure 3 - 14 Daily number of flushes averaged from multiple sources

Therefore, an average daily toilet water consumption of 12.12 L/flush (Figure 3 - 13) and an average number of flushes of 5 flushes/person/day (Figure 3 - 14) means that typical toilet water consumes 61 L/person/day. This value exceeds Las Vegas hotels' estimated daily toilet water consumption of 41 L/person/day (Pacific Institute, 2006).

To estimate the hotel's toilet water consumption per room, the number of flushes per room needs to be determined.

Data collected and analyzed from several studies (Paschke et al. 2002; Pacific Institute, 2006; GLS Research 2006) is shown in Figure 3 - 15. The total number of flushes in the hotel is 9 flushes/room/day from all the studies. The remaining statistics are shown in the figure below.

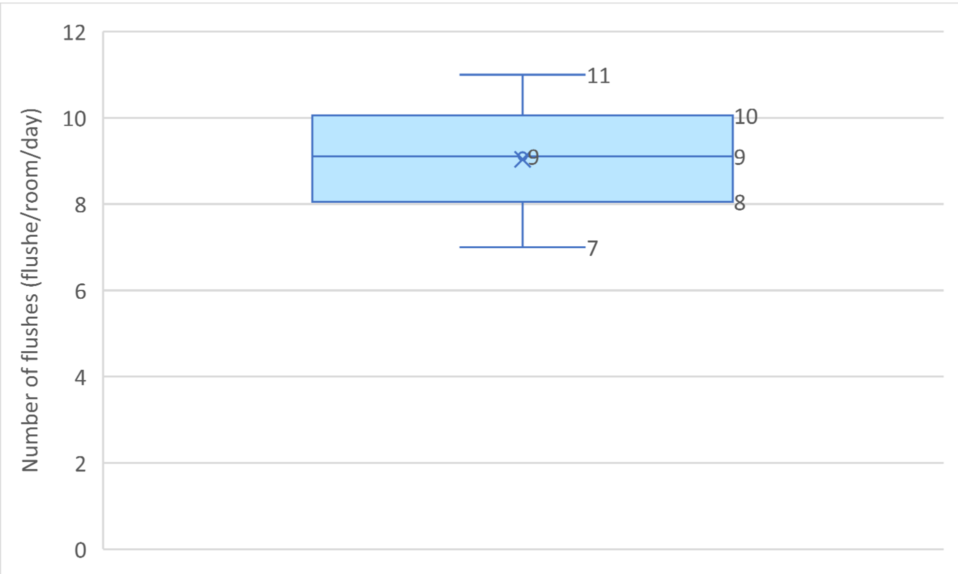


Figure 3 - 15 Daily number of flushes per room in hotel averaged from multiple sources

Therefore, an average daily toilet water consumption per room of 12.12 L/flush (Figure 3 - 13) and an average number of flushes of 9 flush/room/day (Figure 3 - 15) means that typical toilet water in the hotel consumes 109 L/room/day.

3.3.1.1.2 Kitchen water consumption and analysis

One of the hotel facilities is the kitchen used by residential hotel guests and guests from outside. Consequently, hotel occupancy levels may not be related to the number of meals made and change notably from time to time during the year (Shiming, D., 2002).

Kitchen water use is influenced by its operational factor and relies on the type of kitchen. For example, a western kitchen usually consumes less water than a Chinese kitchen for the same amount of meals (Shiming, D, 2002).

In 1990, a major study was conducted to highlight the amount of water consumption in American hotels and motels. Redlin and his colleague deRoos collected questionnaire results from 1600 hotels. The results showed that the kitchen or restaurant percentage water consumption is in the range of 0.05%-25% of hotel water consumption, with a median value of 6% based on the number of meals ranging from 9-60 L/meal/day, with a median of 45 L/meal/day (Redlin and deRoos, 1990).

In 1998, the Greater Vancouver Regional District conducted the "Study of Water Consumption and Conservation Potential in Greater Vancouver's Hotel Industry." This study calculated water consumption based on the end use for selected hotels and from billing data. The results showed that the hotel kitchen or restaurant water consumption is based on the number of rooms in the average range of 11-64 L/room/day with extreme upper consumption of 277 L/room/day (Greater Vancouver Regional District, 1998).

In 1999, Dr Joth Singh and Francine Clouden conducted a study that analyzed the impact of water consumption practices and possible developments at hotels on the islands of Barbados and St Lucia. Using water consumption audits, the study estimated that average kitchen water consumption percentages are 20% of total hotel water consumption (Almeida, 2017).

In 2002, Paschke, van Gelder, and Siegelbaum conducted a comprehensive study to calculate baseline water usage in hotels and determine the feasibility of water conservation in hotel facilities. The data collected came from contacting public and private organizations and literature review. This study showed that the average water consumption of kitchens or hotel restaurants was 200 L/room/day (Paschke et al., 2002).

In Hong Kong, a comprehensive analysis of hotel water consumption was conducted for seven hotel kitchens. Their average water consumption was 96,146 L/day, representing 22% of hotel water consumption with laundry and 55% without laundry (Shiming, D., 2002). This means kitchen or restaurant water consumption of 214 L/room/day with laundry and 543 L/room/day without laundry (Shiming, 2002).

Hotel restaurant seating capacity was 200-224 based on 184 Hilton International and Scandic European hotels (Bohdanowicz and Martinac, 2007a). Serving one meal in a restaurant requires about 35–45 L of water, considerably impacting the hotel's total water consumption (N.E. Matson and M.A. Piette, 2005).

A 2007 paper reported a study of water and energy consumption in 184 Hilton International and Scandic European hotels. The study investigated the characteristics of the hotels and documented the differences in consumption while analyzing resource consumption from water and energy suppliers' databases. The detailed analysis and research illustrated that restaurant seating capacity is 200 to 224 seats (Bohdanowicz and Martinac, 2007a).

In 2012, a study of water consumption in two Malaysian resorts was conducted by Tang (2012). to reduce resort water consumption and develop a base water consumption number. The outcome in the kitchen water consumption was estimated to be 10890 L/day for resort A and 14838 L/day for resort B, representing 6% and 5%, respectively, of total resort consumption. The consumption was based on the number of guests, namely 55 L/guest/day and 48 L/guest/day, respectively and based on the number of rooms which was 93 L/room/day and 67 L/room/day, respectively, where the duties of these kitchens (in addition to food preparation) included only minor dishwashing (Tang, 2012).

Research held in Barcelona hotels attempted to characterize the link between water consumption behaviour and hotel category. It showed that more than 92% of the hotels studied had at least one on-site kitchen and restaurant. Of these, 70.4% had full meal service (breakfast, lunch and dinner) (Dinarès and Saurí, 2015). Also, 70.4% of hotel restaurants were open to guests and the public. The results show no statistically significant changes in water consumption regarding the type or number of meals served, guests type and hotel category (Dinarès and Saurí, 2015).

Water consumption in kitchens must be analyzed to quantify water volume and identify unitary water consumption. To determine the amount of water consumption in the kitchen per room in the hotel, kitchen water consumption can be analyzed by determining percentages and consumption contributions of total hotel water consumption. It is to be noted that the kitchen analysis is not limited to the hotel sector only but can be used for other calculations based on similarities.

The kitchen water consumption concerning total hotel water consumption is shown in Figure 3 - 16, which presents the data collected and analyzed from several studies (Tang, 2012; Shiming, D., 2002; Joth and Francine, 1999; Schultz Communications, Albuquerque 1999; Paschke et al. 2002; Almeida 2017 and Albrecht et al. 2009). From all the studies, the resulting average contribution is 21%. This result is like the kitchen consumption share within the total water consumption in German hotels, where kitchen water contribution was 22% (Styles et al. 2013). The remaining statistics are shown in the figure below.

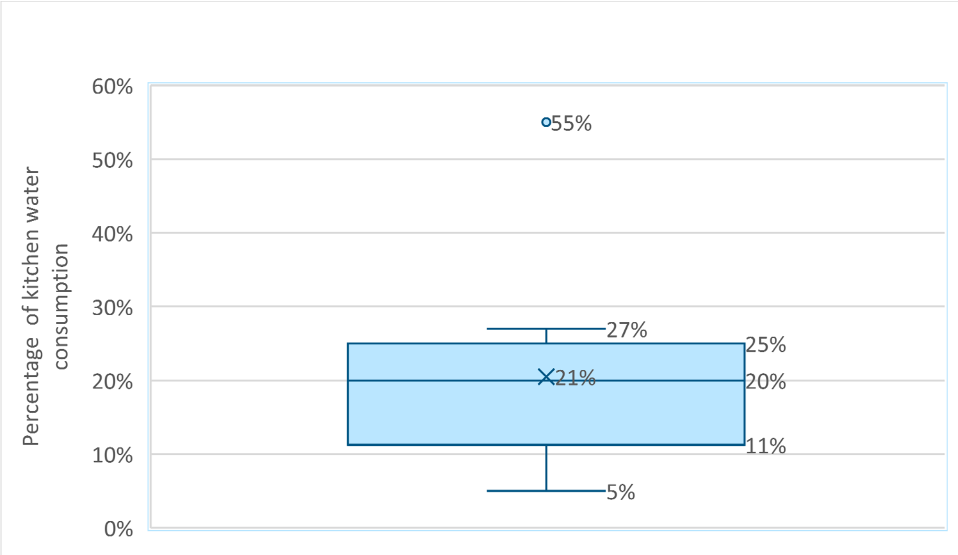


Figure 3 - 16 Kitchen water consumption expressed as a percentage of total hotel water consumption

Besides, the average kitchen water consumption (in L/d) is shown in Figure 3 - 17, which presents the data collected and analyzed from several studies (Tang, 2012; Shiming, 2002; Paschke et al., 2002). From all the studies, the resulting average water consumed is 86,586 L/day. The remaining statistics are shown in the figure below.

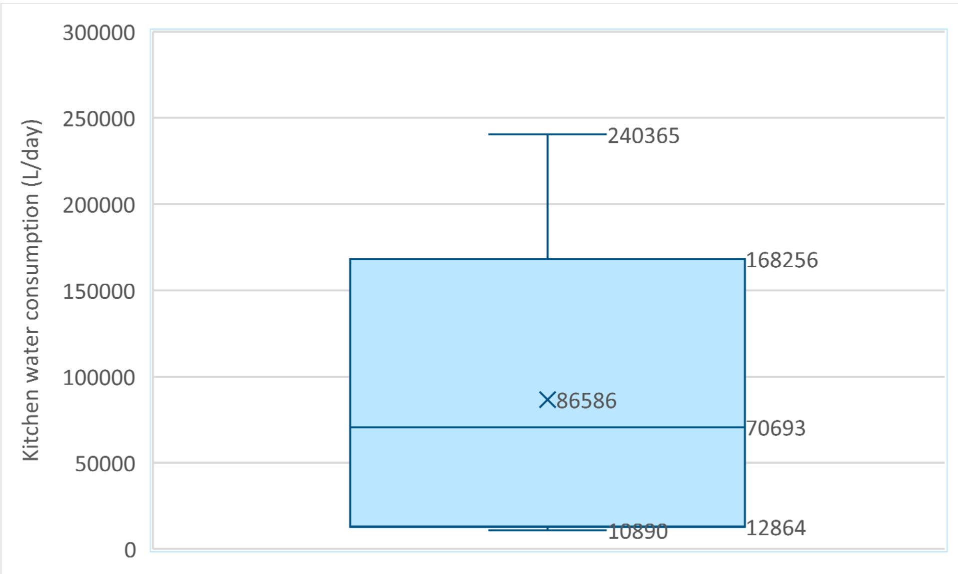


Figure 3 - 17 Daily water consumption in the kitchen

We can calculate an average water consumption per room, considering the number of rooms in the hotel Figure 3 - 18 presents the data collected and analyzed from several studies (Tang, 2012; Shiming, D., 2002; Paschke et al., 2002 and Greater Vancouver Regional District, 1998). From all the studies, the resulting average consumption in the kitchen is 171 L/room/day. The remaining statistics are shown in the figure below.

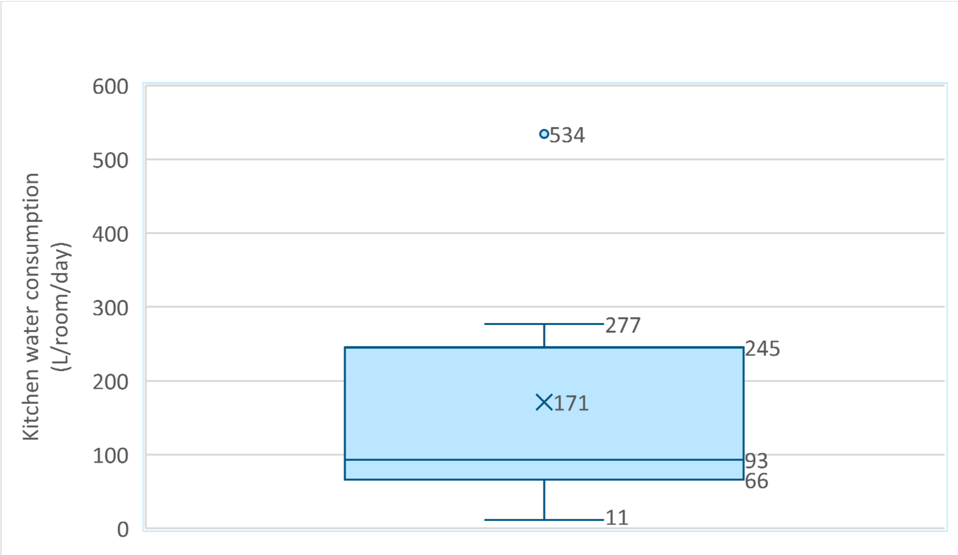


Figure 3 - 18 Daily water consumption in the kitchen per hotel

Based on the analysis of data compiled from previous studies, it is concluded that the variation in the amount of kitchen water consumption is due to the following reasons:

– The occupancy levels change considerably from time to time over a year (Shiming, D., 2002). So different results may be found in different intervals over the year and in different studies.
– The seating capacity and occupancy rate difference affect water consumption (Shiming, 2002).
– Kitchens are open to hotel guests and the general public (Shiming, 2002).
– Water consumption in kitchens may also rely on the type of dishes served (Shiming, D., 2002). For example, preparing a Chinese dish would consume more water than a western dish for the same amount of food.
– Worker behaviour toward the water consumption habit in the kitchen (Epa, 2012; Paschke et al., 2002).
– One hotel may have one or more kitchen services (Paul, 2011).
– The type of equipment used in the kitchen in terms of efficiency significantly impacts water consumption (Epa, 2012).
– The ways of approaching water consumption in the kitchen.

3.3.1.1.3 Laundry water consumption

Large volumes of water are consumed in laundries by commercial, industrial and institutional facilities that wash linens, clothes and other items for hotels and motels, hospitals, nursing homes, prisons, universities and restaurants. The amount of water used in laundries is for operations which contain the wash and rinse cycles of washing machines, steam-heated dryers, steam-pressing equipment, and the reclamation of dry solvent (Albrecht et al., 2009).

The presence of laundries would significantly affect the total water use in a hotel (Shiming, D., 2002), where they use in the range of 2-16% of the total water consumption (Dinarès and Saurí, 2015).

Today, there are different kinds of washing machines, and there is a difference in how much water they consume when they are full (Rochelle Leggett, 2018).

High-efficiency washing machines are front-loading, meaning that the laundry is added from the door in front, and use a tumbling action that cleans by repeatedly lifting and dropping clothes over a small pool of water (Rochelle Leggett, 2018 and DeOreo and Mayer, 2014). There are different types of high-efficiency washing machines. The difference is in water consumption efficiency, which ranges from 57-95 L/load to 114 L/load of clothes (Rochelle Leggett, 2018). This type of machine does not need as much water as typical (top-loading) washing machines (DeOreo and Mayer, 2014).

In 1990, the American Hotel and Motel Association accomplished a study of over 1,600 hotels which showed that in-house laundry hotel water per kg of laundry weight was 8.3-49 L/kg of laundry and the laundry in a guest room in the range of 2.7-8.6 kg/room/day with a median of 4.5 kg/room/day (American Hotel and Motel Association, 1990). Also, it was estimated that weighted laundry in hotels fell in the range of 3.6-5.4 kg/room/day with an average of 4.5 kg/room/day (Pellerin Milnor, 1990).

In 1990 and after, laundry water consumption in residential dwellings decreased from 155 L/load to 118 L/load (Deoreo et al., 2016). This estimation is similar to the "Residential End Uses of Water Study 2013 Update" result, where the amount of water consumption in laundry per load was in the range of 155-118 L/load (DeOreo and Mayer, 2014), while the efficient laundry used less than 57 L/load (DeOreo and Mayer, 2014). The average number of loads washed per person per day was 0.3 load/person/day (DeOreo and Mayer, 2014).

In 408 hotels across the U.S. in 1990, a study on the laundry facilities regarding hotel water consumption showed that laundries used 8.3 to 49.2 L/kg with a median of 20 L/kg of water/clothes (Redlin and deRoos 1990).

In 1997, the average laundry water consumption was 13.9 L/kg. After that, several improvements reduced water consumption to 9.6 L/kg in 2005 (AEA, 2009).
Similarly, according to a UK survey, laundry water consumption was 6.2-11.8 L/kg (Stevens, 2011).

In 1998, the Greater Vancouver Regional District conducted a "Study of Water Consumption and Conservation Potential in Greater Vancouver's Hotel Industry." This study calculated water consumption based on end-use for selected hotels and from billing data. The result showed that the hotel's laundry water consumption based on the number of rooms was in the average range of 38-106 L/room/day, and the extreme upper consumption was 273 L/room/day (Greater Vancouver Regional District, 1998). Another study estimated that water consumption, based on the number of rooms, was in the average range of 40-16 L/room/day with an average laundry weight of 2.5-6 kg/room/day (Styles et al. 2013).

Based on 1,188 homes, the average number of loads washed of laundry per day was 0.96 load/day, the average litres per load of clothes was 155 L/load with a standard deviation of 46 L/load and a median volume of 150 L/load of Laundry, with an average of 0.37 load/person/day (Mayer et al. 1999).

Coin-operated washing machines consume 12.4 m^3/apartment. Whereas normal washing machines consume 4.6 m^3/apartment of water annually (Schultz Communications, Albuquerque,1999).

An international hotel environment initiative estimated that 10% of the total water consumption was used by laundries, equivalent to the consumption of 51 L/room/day (USAID, 2001).

According to a hotel water conservation study, hotel laundries consume 114 L/room/day, with weighted material consuming 16.7 L/kg (Paschke et al. 2002).

In 2004, a Department of Energy study analyzed that new commercial laundries use an average of 129 L/load, while Energy Star qualified laundry machines use 76 L/load (U.S. EPA and U.S. DOE 2004).

The Seattle Public Utilities Commission (SPUC) estimated that hotel guests use 5.4 kg/room/day (SPUC 2002). If an average occupancy rate is calculated as 2.1 guest/room, this corresponds to 2.6 Kg/guest/day (Pacific Institute, 2006).

The average laundry water consumption in Las Vegas was 21 L/kg (Pacific Institute, 2006).

The statistical analysis of a 184 hotel sample investigation showed that the mean laundry value in Hilton hotels was 4.14 kg/guest, and the water consumption per guest was 515.6 L/guest/day. In contrast, the mean laundry value in Scandic hotels was 2.02 kg/guest, and the water consumption per guest was 215.5 L/guest/day (Bohdanowicz and Martinac, 2007). The higher laundry per guest loads in an upscale hotel was because the upscale hotel facilities had sports and health centres, as well as changeable texture weighting material and size of laundry items; for example, the size of towels is large (Bohdanowicz and Martinac, 2007).

The presence of laundry significantly influences water consumption in facilities, where it is estimated that one kilogram of laundry consumes 20-30 L of water (Bohdanowicz and Martinac, 2007).

Different estimations have been done over laundry weight in hotels, where it was estimated in a US study that the range was 2.4-5.8 kg/room/day with a median of 5.4 kg/room/day (O'Neill et al. 2002). Another study estimated 4 kg/room/day (Accor, 2007).

Processing optimisation and water recycling have demonstrated water consumption as low as 2 L/kg (EC, 2007).

From 2005 to 2010, several machine improvements allowed washing machine water consumption to reach 8 L/kg and even as low as 7 L/kg laundry washed in laundries with commercial machines (Hohenstein Institute, 2010). However, the most efficient laundry consumes 5-6 L/kg (Bobák et al., 2010; ITP, 2008) compared to non-efficient small-scale laundry operations, which consume 20 L/kg (Bobák et al., 2010; ITP, 2008). The most common type of laundry machine is washer-extractor which operates with a rotating drum that agitates the laundry during the wash and rinse cycles, then spins it at high speeds to extract and use fresh water each wash and rinse cycle (Albrecht et al., 2009). This washing machine has a capacity of 88 to 100 Kg/load and consumes around 21 to 29 L/kg (Albrecht et al., 2009) or 8.3-16.7 L/kg (Schultz Communications, Albuquerque,1999). A typical washing machine equipped with water efficient laundering equipment, like continuous-batch washers and water reclamation systems, may reduce water consumption by 70% (Albrecht et al., 2009).

The suitable indicator for laundry water efficiency is litre of water per kilogram of textile, and the recommended benchmark for hotels is 5 L/kg and 9 L/kg for restaurant laundry (D. Styles et al. 2013).

According to the United States Environmental Protection Agency (U.S. EPA.), the average laundry water consumption is 117-151 L/load, and the standard laundry machine uses 87 L/load. In contrast, high-efficiency, front-loading washing machines can consume as little as 49 L/load (U.S. EPA, 2017).

Typical washing machines in the US, which are top loading, means that the laundry is filled from the door in the top, and an agitator spins the laundry through the water. When this washing machine is fully loaded, the old model consumes as much as 170 L/load, while the new model consumes 151 L/load or less (Rochelle Leggett, 2018).

Water consumption in the laundries needs to be analyzed to quantify the water volume used and identify unitary water consumption.

The laundry water consumption concerning total hotel water consumption is shown in Figure 3 - 19, which presents the data collected and analyzed from several studies (Tang, 2012; Shiming.D, 2002; Paschke et al., 2002; Styles et al., 2013; Smith et al., 2009; DPPEA 2009; Greater Vancouver Regional District, 1998; Meade and Gonzalez-Morel 2011; Dinarès and Saurí 2015). From all the studies, the resulting average contribution is 15%. The remaining statistics are shown in the figure below.

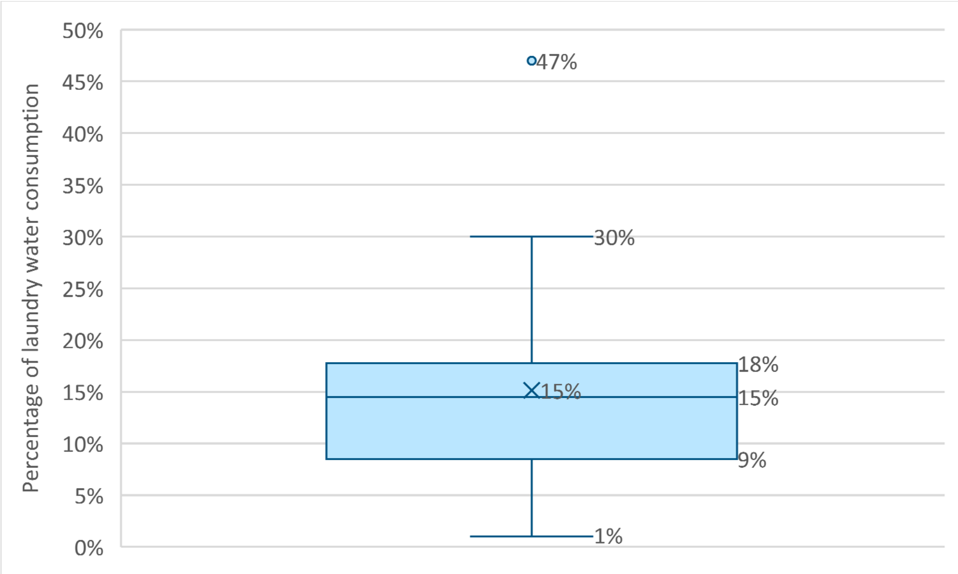


Figure 3 - 19 Laundry water consumption expressed as a percentage of total hotel water consumption

Besides, the average laundry water consumption (in L/d) is shown in Figure 3 - 20, which presents the data collected and analyzed from several studies (Tang, 2012; Bohdanowicz and Martinac,2007; Shiming, 2002; Paschke et al., 2002). From all the studies, the resulting average water consumed is 96,278 L/day. The remaining statistics are shown in the figure below.

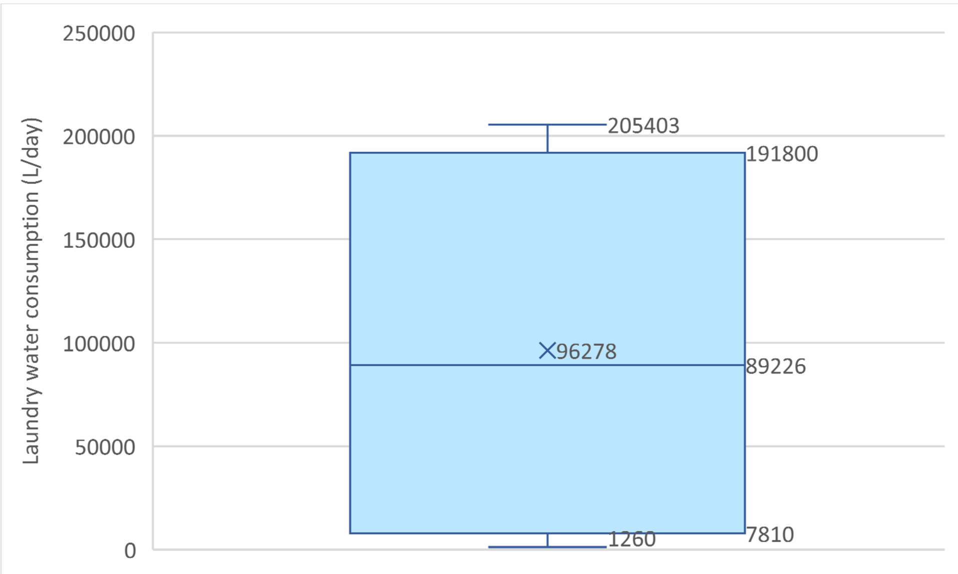


Figure 3 - 20 Daily water consumption in the laundry

Firstly, we can calculate the average water consumption per room, considering the number of rooms in the hotel. Figure 3 - 21 presents the data collected and analyzed from several studies (USAID, 2001; Paschke et al., 2002; American Hotel and Motel Association, 1990; Greater Vancouver Regional District, 1998; Redlin and de Roos. 1990; D. Styles et al.,2013; Tang, 2012; Shiming, 2002). From all the studies, the resulting average consumption in the laundry is 124 L/room/day. The remaining statistics are shown in the figure below.

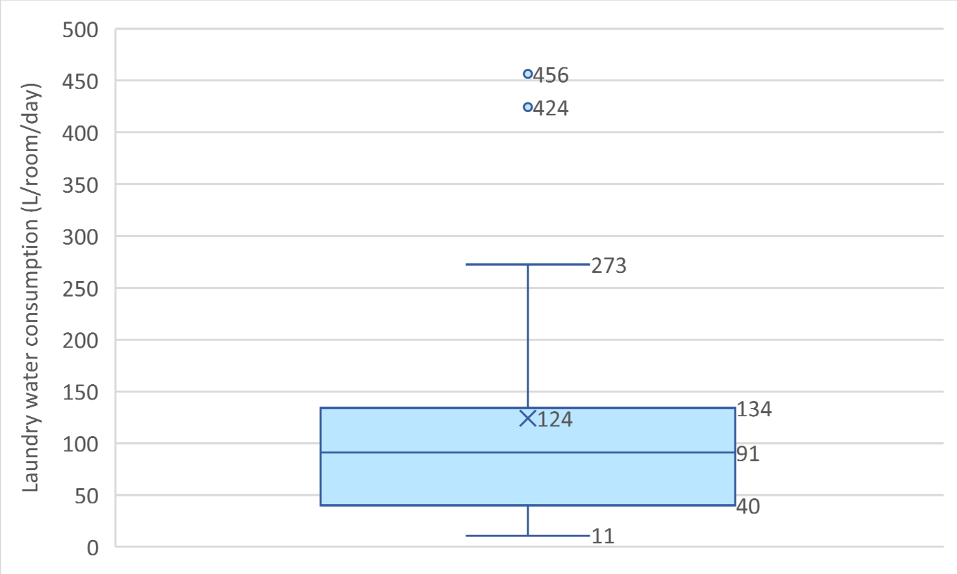


Figure 3 - 21 Daily laundry water consumption per room in a hotel

Secondly, we can calculate the average water consumption per guest, considering the number of guests in the hotel. Figure 3 - 22 presents the data collected and analyzed from several studies (Bohdanowicz and Martinac, 2007; Pellerin Milnor, 1990; Tang, 2012; Paschke et al., 2002). From all the studies, the resulting average consumption in the laundry is 151 L/guest/day. This result is higher than the statistical indicator of more than 184 hotels, 124 L/guest/day (Bohdanowicz and Martinac, 2007). The remaining statistics are shown in the figure below.

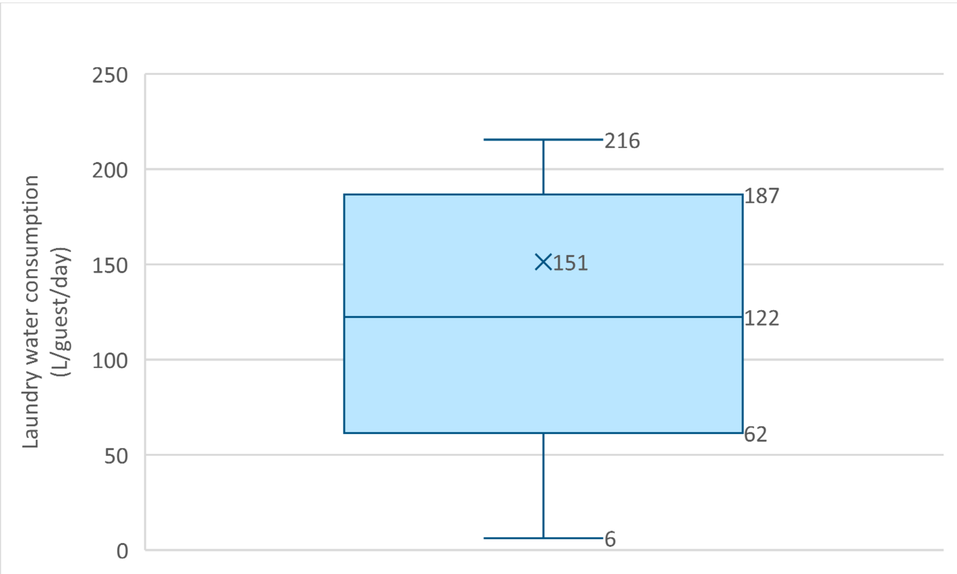


Figure 3 - 22 Daily laundry water consumption per guest in a hotel

Finally, we can calculate an average water consumption per weight, considering the total weight of the laundry. Figure 3 - 23 presents the data collected and analyzed from several studies (Bohdanowicz and Martinac, 2007; Pellerin Milnor, 1990; Tang, 2012; Paschke et al., 2002). From all the studies, the resulting average consumption in the laundry is 20 L/kg/day. This result is the same as the estimated water consumption in the non-efficient small-scale laundry as 20 L/kg/day (Bobák et al., 2010; ITP, 2008). The remaining statistics are shown below.

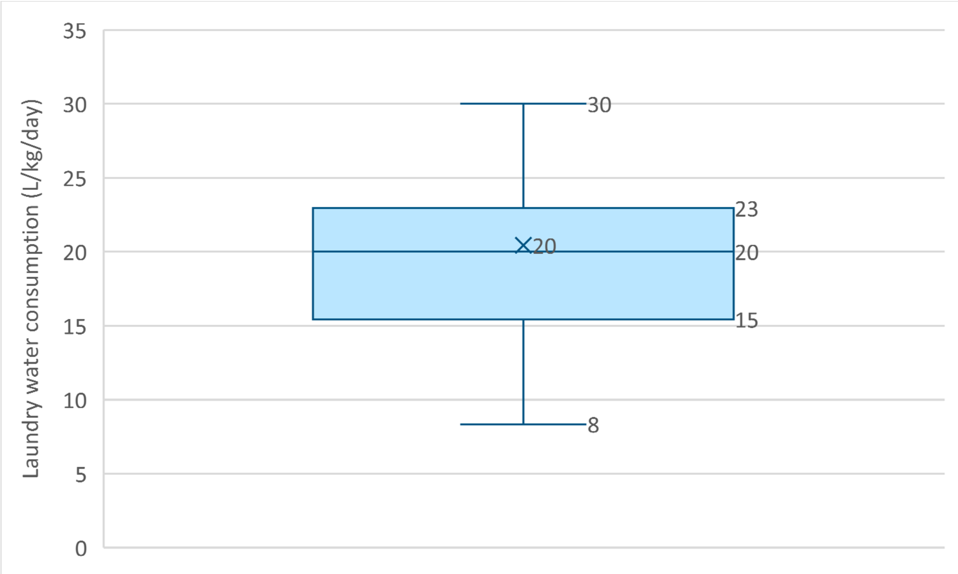


Figure 3 - 23 Daily laundry water consumption per weight

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of laundry water consumption is due to the following reasons:

- Schultz and Albuquerque (1999) and Albrecht et al. (2009) mentioned that some laundries use the last rinse water to start the next load in a new wash cycle to reduce water consumption.
- Joth Singh and Francine Clouden (1999) and Gleick et al. (2003) indicated that laundry services vary from outsourced to in-house.
- Gallons (2001) pointed out that the number of loads washed influences laundry water consumption, where the full load consumes less water than a partial load per laundry weight.
- Gleick et al. (2003) pointed out some laundries applied conservation measures and practices which could cut laundry water consumption by around 50%.
- Troy et al. (2005) indicated that people's behaviour would influence the volume and quality of the laundry.
- Bohdanowicz & Martinac (2007) showed that the variation in laundry loads are partial due to activities in sport and health centres presented in some hotels, as well as the level of textile dirt for each load of laundry, which impacts the variation in water consumption.
- Colorado Water Wise and Aquacraft Inc (2010) indicated that it is evident that the degree of equipment efficiency in laundry and clothes washers impacts the amount of water consumption.
- Meade & Gonzalez-Morel, (2011) indicated that the laundry staff influence the amount of water consumption. So, they need to be developed and trained. Also, it was shown that different types of laundry machines consume different amounts of water.

– The Environmental Protection Agency (2016) indicated that some hotels have installed more water-efficient laundry equipment and encourage their guests to reuse towels and bed linens to reduce water consumption in laundry.

3.3.1.1.4 Irrigation water consumption

Today, landscape irrigation systems are an important element in municipal water. However, the lack of studies on water demand and demand management has resulted in wasteful irrigation practices (Water Research Foundation, 2018). There are limited research studies on irrigation water consumption as well. Most of the literature and program development studies show that water consumption alone does not explain the correlation between the geographical growth of landscaping and irrigation water consumption (Water Research Foundation, 2018).

In 1990, a study completed by American Hotel and Motel Association showed that only 13 out of 1600 hotels provided a readable breakdown of water consumption. The study also found that the irrigation water consumption ranged between 1% to 44% of the total water consumption, with a median of 14%. One of the hotels in Washington State, with an area of 20,234 m^2, reported the consumption of 1,893 L/day of irrigation water, equivalent to 10% of total hotel water consumption, equal to 68 L/room/day (American Hotel and Motel Association, 1990). In Greater Vancouver Regional District, the irrigation water consumption calculated by an End Use study showed that the irrigation water consumption per room was 3.3%, equivalent to about 53 L/room/day (American Hotel and Motel Association, 1990).

In Greater Vancouver Regional District, the irrigation water consumption calculated by an End Use study showed that the irrigation water consumption percentage out of the total hotel water consumption per room was 3.3%, equivalent to about 53 L/room/day (Greater Vancouver Regional District, 1998).

Mayer et al. (1999) reported that irrigation water consumption in the 2.55 to 2.27 L/m2/day exhibits a relatively strong positive correlation with irrigation area (irrigable portion).

According to the International Hotel Environment initiative, the estimated percentage of irrigation water consumption was 15% out of the total hotel water consumption, equivalent to 66 L/room/day to 88 L/room/day with an average of 76 L/room/day (USAID, 2001). At Utah State University, urban landscape water irrigation accounts for up to 65% of the total annual municipal water consumption (Utah State University, 2016), while at North Carolina University, the percentage of irrigation water consumption averaged 20%-30% of the total water used in a facility per year (Albrecht et al., 2009).

Across 57 irrigation areas, equal to 104,186.78 m^2, the average daily water consumption was 6.29 L/m^2/day with a minimum of 3.8 L/m^2/day (Seliger, 2018). When the irrigation system was covered with ungroomed grass of 55,835.16 (m^2), it consumed around 0.39 L/m^2/day. When the irrigation system was covered with turf, mulch, or any non-grass, the consumption was approximately 4.7-6.29 L/m^2/day (Seliger, 2018).

Water consumption in irrigation needs to be analyzed to quantify the water volume used and identify unitary water consumption. To determine the amount of water consumption in the irrigation per room in the hotel and per irrigation area, irrigation water consumption can be analyzed by determining percentages and consumption contributions of total hotel water consumption and irrigation water consumption. It is to be noted that the irrigation analysis is not limited to the hotel sector only but can be used for other calculations based on similarities.

The irrigation water consumption concerning the total hotel water consumption is shown in Figure 3 - 24, which presents the data collected and analyzed from several studies (Albrecht et al., 2009; American Hotel and Motel Association, 1990; Schultz Communications, Albuquerque 1999; Greater Vancouver Regional District, 1998; US EPA 2009; Meade and Gonzalez-Morel 2011; Mayer et al., 1999). From all the studies, the resulting average contribution is 18%. This result is like the irrigation consumption share within the total water consumption in American hotels, where irrigation water contribution was 22% (Environmental Protection Agency, 2016). The remaining statistics are shown in the figure below.

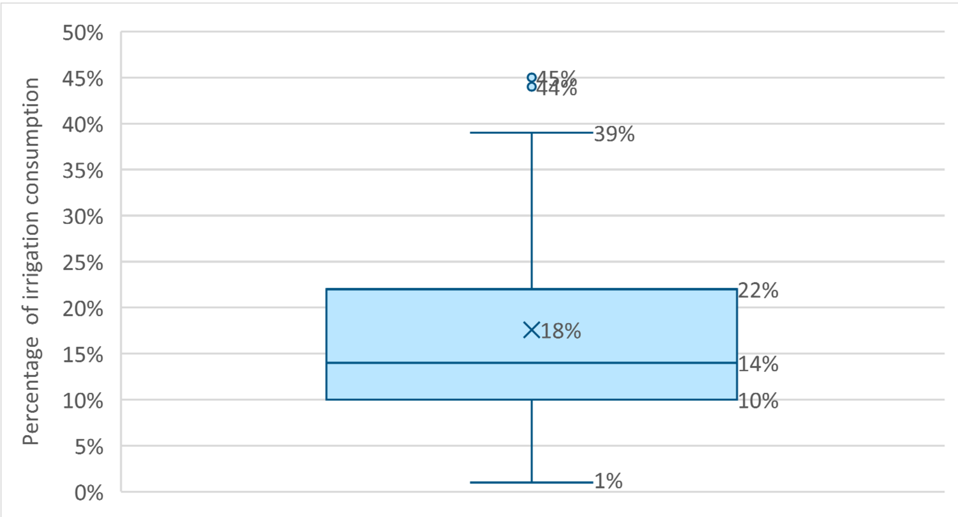


Figure 3 - 24 Irrigation water consumption expressed as a percentage of total hotel water consumption

Besides, the average irrigation water consumption per hotel (in L/d) is shown in Figure 3 - 25, which presents the data collected and analyzed from several studies (Seliger, 2018; Tang, 2012; Albrecht et al. 2009). From all the studies, the resulting average water consumed is 330,958 L/day. The remaining statistics are shown in the figure below.

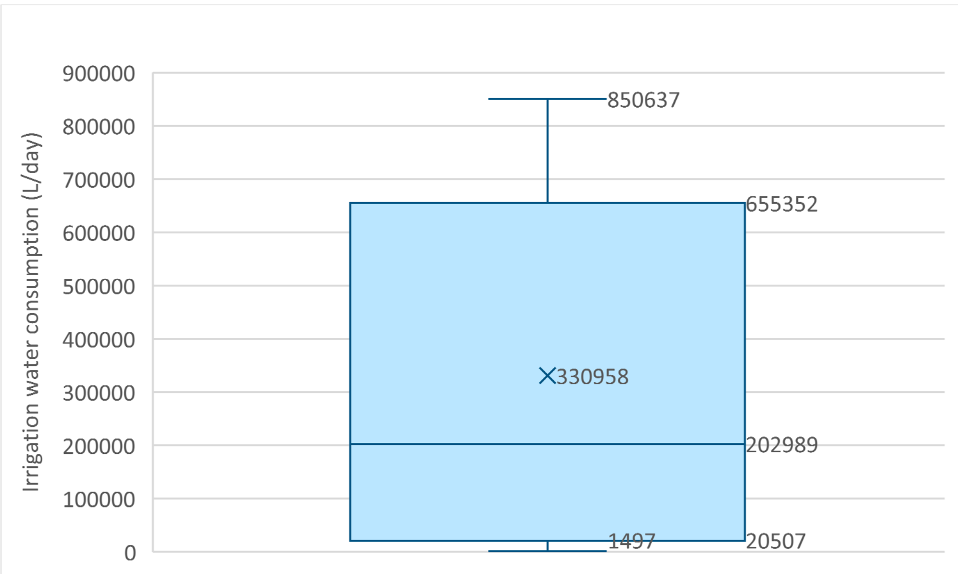


Figure 3 - 25 Irrigation water consumption per hotel

We can calculate the average water consumption per room, considering the number of rooms in the hotel. Figure 3 - 26 presents the data collected and analyzed from several studies (USAID, 2001; Albrecht et al., 1998; Greater Vancouver Regional District, 1998; Tang, 2012). From all the studies, the resulting average consumption in irrigation is 70 L/room/day. The remaining statistics are shown in the figure below.

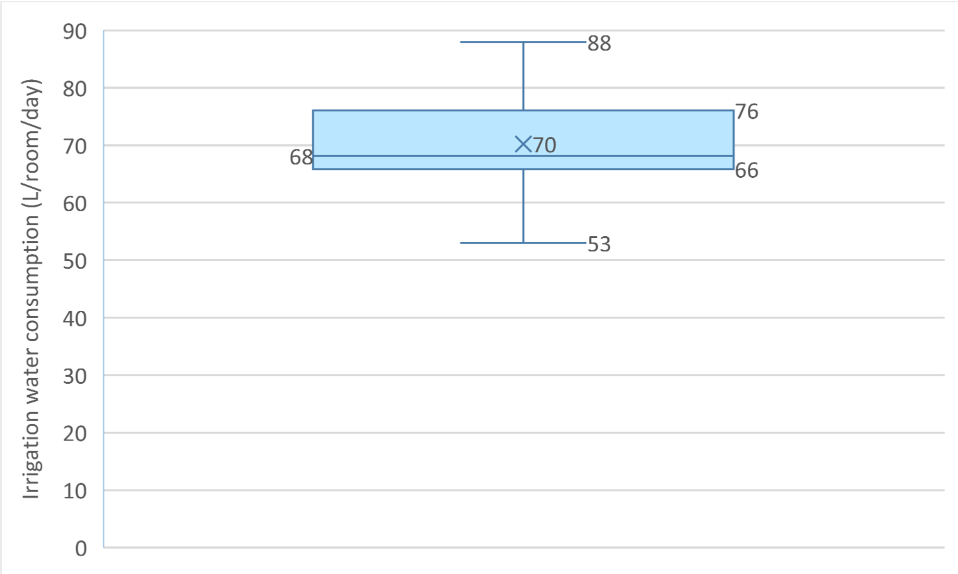


Figure 3 - 26 Daily irrigation water consumption per room in a hotel

Similarly, we can calculate an average water consumption per irrigation area, considering all the areas, as shown by Figure 3 - 27, which presents the data collected and analyzed from several studies (Seliger,2018; Mayer et al., 1999; Albrecht et al. 2009; Schultz Communications, Albuquerque 1999). From all the studies, the resulting average consumption in irrigation is 3.45 L/m²/day. This result is like the estimated value of the water consumption patterns study in the irrigation, which was 3 L/m²/day (Tang, 2012). The remaining statistics are shown in the figure below.

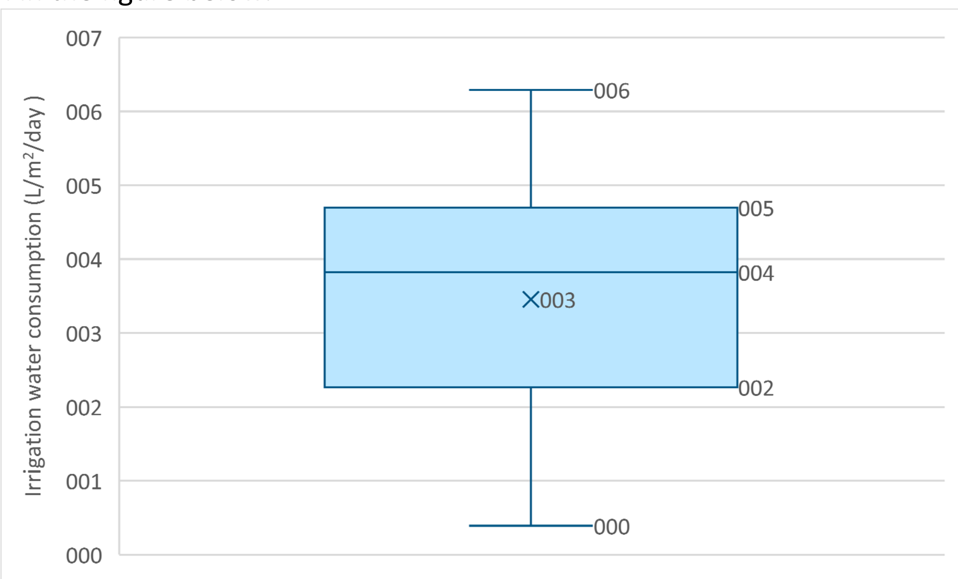


Figure 3 - 27 Daily irrigation water consumption per irrigation area

Based on the data collected and analyzed from several studies (DeOreo et al., 1999; Seliger, 2018; Tang, 2012; Albrecht et al., 1998), a variation in irrigation water consumption concerning the irrigation area is shown in
Figure 3 - *28*. From all the studies, the highest water consumption value per irrigation area is about 6.29 L/m^2/day, and its irrigation area is about 104,187 m^2. In contrast, the lowest water consumption per irrigation area is about 0.39 L/m^2/day, and its irrigation area is about 5,213 m^2.

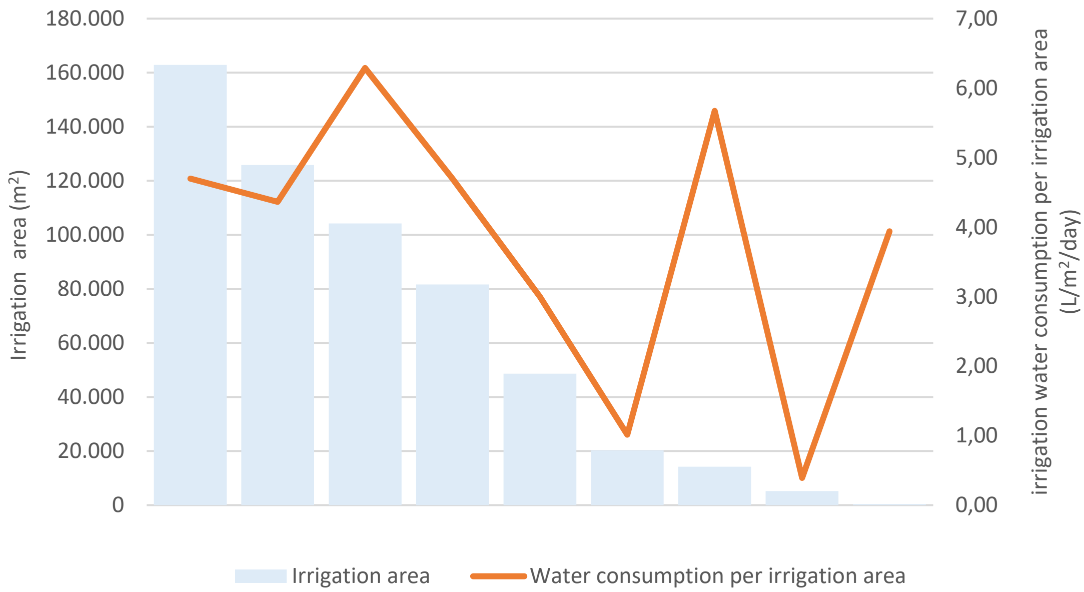


Figure 3 - 28 Irrigation area vs irrigation water consumption

Based on the data collected and analyzed from several studies (Seliger, 2018; Albrecht et al., 2009; Tang, 2012; Mayer et al., 1999; Schultz Communications, Albuquerque, 1999; Greater Vancouver Regional District, 1998), a plot of irrigation water consumption per irrigation area and an irrigation area presented in Figure 3 - 29 indicates a positive correlation between the two. It indicates a maximum water consumption threshold beyond which the per unit area water consumption increase with an increase in the area.

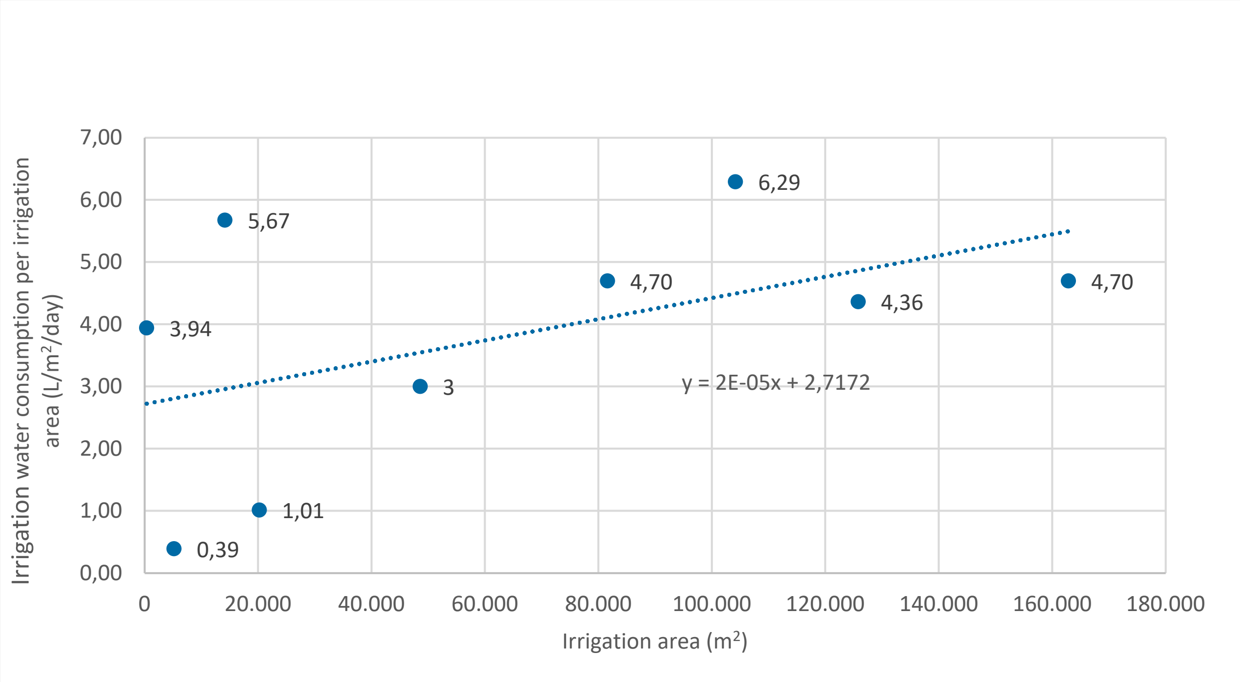


Figure 3 - 29 Correlation between irrigation water consumption per irrigation area and irrigation area

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of irrigation water consumption is due to the following reasons:

- Jensen et al. (1990), Azhar et al. (2010) and Azhar et al. (2011) pointed out that poor water irrigation management is the most common reason for inefficient water use in irrigation and the variation in the amount of water consumption.
- Bohdanowicz & Martinac (2007) proved a strong correlation between water consumption and irrigation area in warm climates, indicative of considerable irrigation needs in these areas, compared to temperate zones.
- Omran (2008) and Azhar and Perera (2011) pointed out a wide range of alternatives available for irrigation methods that consume different amounts of water. For example, drip irrigation can be used effectively to reduce water consumption.
- Azhar (2011) clarified that irrigation water consumption is affected by different factors, such as water availability, system design, technique, nature of the soil and its properties, and behaviour practice.
- Hatfield et al. (2001) showed that it is possible to decrease irrigation water consumption by 25% to 40% through tillage practices and by 15% to 25% through soil nutrient management.
- Edmunds & Associates (2010) mentioned that irrigation water consumption can be affected by different factors such as weather, soils, vegetation, and the extent of irrigation area influenced by water consumption. Other factors Vickers (2001) mentioned, which have the same effect, were water cost, precipitation, and climate.

3.3.1.1.5 Cooling and heating water consumption

Cooling towers are types of air-conditioning systems that benefit from the cooling resulting from water's evaporation to take away heat from it as it circulates through the Heating, Ventilation, and Air-Conditioning (HVAC) chillers (Smith et al. 2009). Cooling towers are considered one of the biggest causes of increased water consumption in the commercial and industrial fields (Albrecht et al., 2009). This consumption results from evaporation, the water misting and drifting away (Smith et al.2009). Cooling and heating are responsible for consuming between 10% to 15% of hotel water (Smith et al., 2009) and can be as high as 30% (Albrecht et al., 2009). This variation in water consumption in cooling and heating systems may be due to differences in their maintenance level. The cooling and heating may consume more water than all toilets, hand basins and showers combined (Smith et al.2009).

A survey was conducted in a hotel with 900 rooms in Los Angeles. The average water consumption from January through December was 821,055 L/day, equivalent to 912 L/room/day. HVAC (primarily cooling tower evaporation) water consumption is estimated to represent 30% of the total average water consumption in the hotel, equivalent to 24317 L/day or 274 L/room/day. (Brown and Caldwell Consultants 1991).

Based on 500 telephone interviews and 657 on-site surveys in hotels/motels, it was found that the hotel heating and cooling system consumed 46% of the hotel's total water consumption (East Bay Municipal Utility District, 1994).

According to Seattle, Washington, Seattle Public Utilities (SPU) and their consultant team implemented a “Hotel Water Conservation Pilot Project from 1999 until 2001”. The two hotels were studied in a yearlong study. The first hotel reported consumption in the range of 2623 L/day to 75076 L/day, equivalent to 3 L/room/day and 83 L/room/day. Its average ranged over the year from 22588 L/day to 46465 L/day, equaling 27 L/room/day and 53 /room/day, respectively (O’Neill et al.2002). The second hotel data indicated that the peak time of the cooling and heating occurred in June. This peak consumption resulted in an average of 31078 L/day to 43017 L/day over three years, accounting for 24% to 33% of total hotel water consumption. In addition, the total hotel water consumption was estimated at 157 L/room/day, and the cooling and heating water consumed was estimated at 43 L/room/day in the peak time (O’Neill et al.2002).

According to studies and data analysis of water consumption end use in 17 hotels, cooling and heating consumption stayed at 1% to 21% of the total hotel water, with an average of 9%. (P. Paschke et al. 2002). In Sheraton Suites Galleria, the cooling and heating consumption was estimated at around 16% of total water consumption (Resort, 2006). Their estimation aligns with New Mexico Office of the State Engineer readings reported in "Water Conservation Handbook for Commercial, Institutional, and Industrial Users," which shows that cooling and heating consume 15% of the total hotel water consumption (Resort, 2006).

According to water efficiency consumption in the commercial and institutional sector for the “WaterSense Program”, water consumption in cooling and heating was estimated to be 11% of the total hotel water consumption (US EPA, 2009). The hotel location affects the amount of water consumption in cooling and heating. In Australia, the result of the survey and audit showed that around 10% of total water consumption in hotels (Smith et al., 2009). While, in the US, the cooling and heating in Denver reported a consumption of around 18.43% (US EPA, 2009). In Pittsburgh, it was 15% of the total hotel water consumption. Water meter measurements in hotels show that cooling heating consumption is around 0.4% (Tuppen, 2013) to 4% of total water consumption (Rajini and Samarakoon, 2016).

Water consumption in cooling and heating is strongly correlated with the cooling and heating equipment capacity, which depends on the cooled and heated space (Kieger et al. 2015). Also, in facilities and buildings, this consumption depends on the occupancy (i.e., the number of people at the property and cooling and heating area (Kieger et al. 2015).

Water consumption in the cooling and heating system must be analyzed to quantify the water volume and identify unitary water consumption. It is to be noted that the cooling and heating analysis is not limited to the hotel sector only but can be used for other calculations based on similarities.

The cooling and heating water consumption with respect to total hotel water consumption is shown in Figure 3 - 30, which presents the data collected and analyzed from several studies (Smith et al., 2009; Albrecht et al., 2009; Rajini and Samarakoon 2016; Tuppen, 2013; US EA 2009; Resort 2006; P. Paschke et al. 2002 and O'Neill et al.2002). From all the studies, the resulting average contribution is 14%. This result is like the cooling and heating consumption share within the total water consumption in American hotels, where cooling and heating water contribution was 12% (Environmental Protection Agency, 2016). The remaining statistics are shown in the figure below.

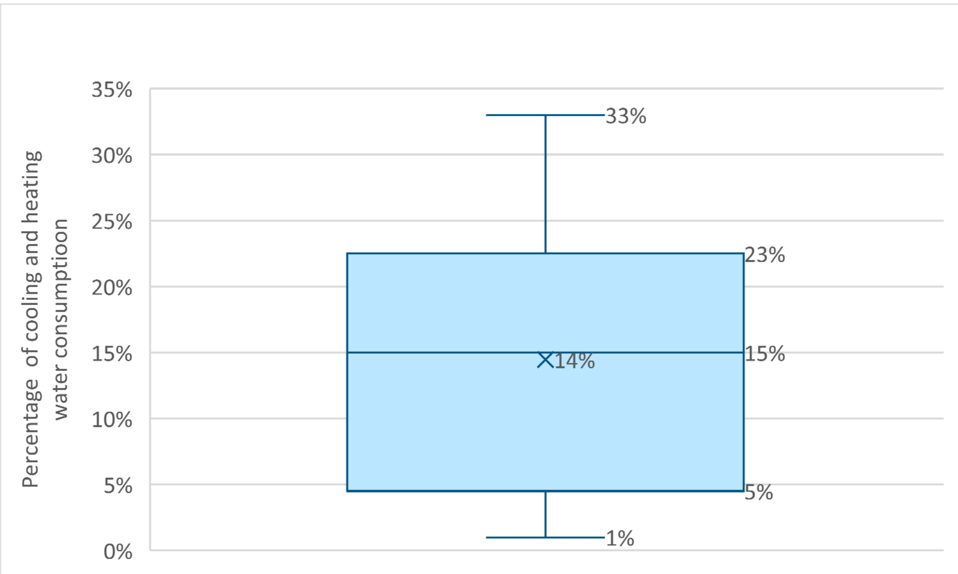


Figure 3 - 30 Cooling and heating water consumption expressed as a percentage of total hotel water consumption

Besides, the average cooling and heating water consumption per hotel (in L/d) is shown in Figure 3 - 31, which presents the data collected and analyzed from several studies (O'Neill et al.2002). From all the studies, the resulting average water consumed is 36,808 L/day. The remaining statistics are shown in the figure below.

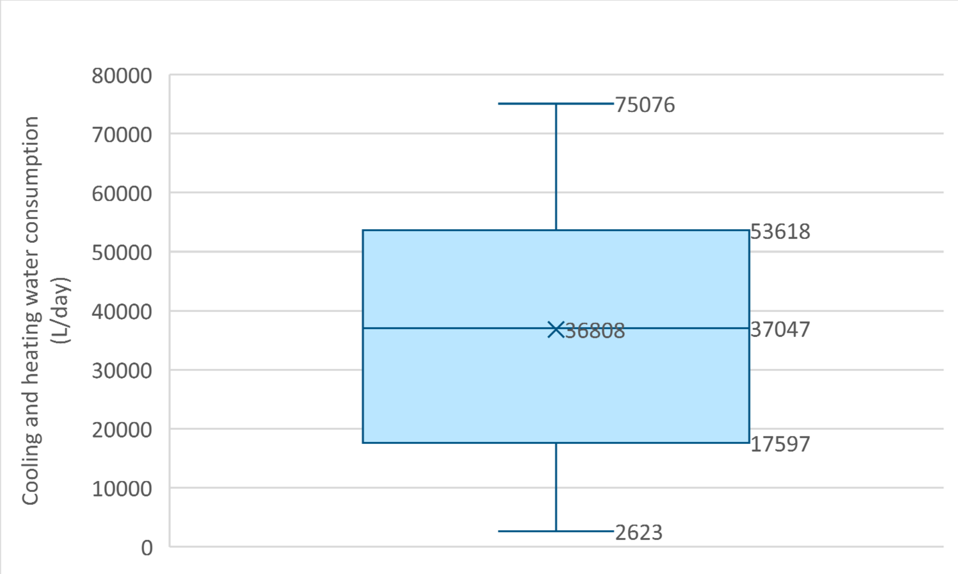


Figure 3 - 31 Daily cooling and heating water consumption

We can calculate the average water consumption per room in a hotel, considering the number of rooms in the hotel. Figure 3 - 32 presents the data collected and analyzed from several studies (O'Neill et al.2002). From all the studies, the resulting average consumption in cooling and heating is 42 L/room/day. The remaining statistics are shown in the figure below.

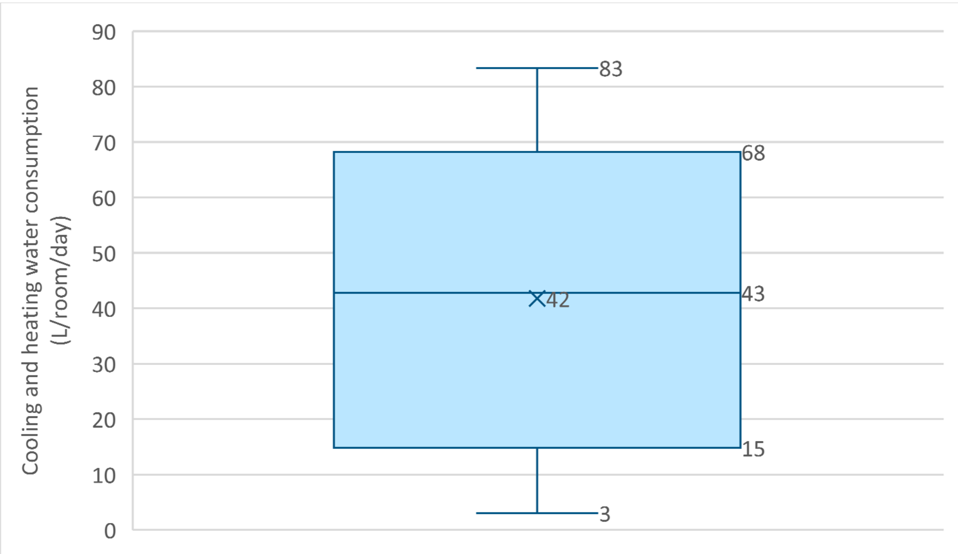


Figure 3 - 32 Daily cooling and heating water consumption per room in a hotel

Similarly, we can calculate the average water consumption per area, considering the total cooling and heating areas. Figure 3 - 33 presents the data collected and analyzed from several studies (Water 2007; Dziegielewski et al. 2000; Africa 2009). From all the studies, the resulting average consumption in cooling and heating is 0.9 L/m^2/day. The remaining statistics are shown in the figure below.

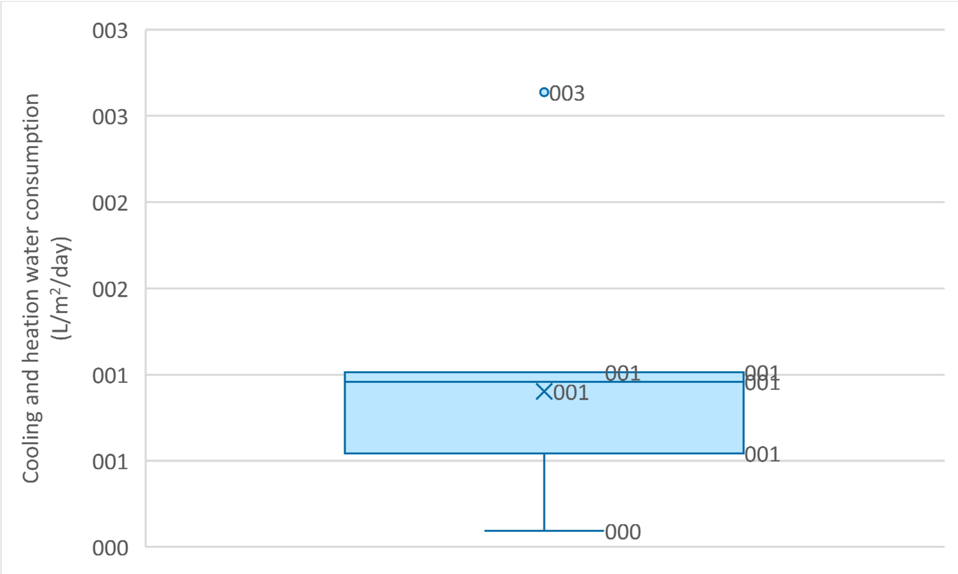


Figure 3 - 33 Daily cooling and heating water consumption per area

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of cooling and heating water consumption is due to the following reasons:

– Paschke et al. (2002) mentioned that facilities used different cooling systems types. The open-loop generator cooling system consumes more water than a closed-loop generator cooling system due to recycles water from onsite cooling.
– Colorado WaterWise (2010) indicated that eliminating single-pass cooling, increasing the tower's cycles of concentration, improving total operational management, and water efficiency significantly impact the amount of water consumed.
– According to standards in the "Efficient Use of Water in Building, Site and Mechanical Systems," the buildings' design greatly impacts the cooling and heating water consumption.
– Haljamäe (2011) showed that the cooling and heating design loads impact the amount of consumed water.

3.3.1.1.6 Swimming pool water consumption

Despite requiring large volumes of water for the operation, only a few studies have been conducted on the swimming pools water consumption (Comissão Europeia, 2013; Maglionico and Stojkov, 2015). Swimming pools have a significant environmental footprint concerning water, energy and chemical needs, particularly if poorly maintained. For example, a 300 m^2 indoor swimming pool, when heated at 25 degrees, can lose 21000 litres of water per week due to water evaporation at a temperature of 28 C^o, air temperature of 29 C^o, and humidity of 60% (Business Link, 2018).

One of the best ways to calculate the water consumption in a swimming pool is through the index litre per user. But this index cannot be certainly recorded in accommodation places where surveys may be required. So, the pool area's water consumption index per square meter can be a better alternative (Comissão Europeia 2013). In a German hotel, sub-metering data for a swimming pool showed that its water consumption was 52 L/guest/day, including showers and toilets, etc., based on the assumption of 100 guests per day. (Comissão Europeia, 2013). This is close to what has been proposed by Ecotrans (2006) that the average water consumption of a swimming pool is 60 L/guest/day in accommodation places.

In 2012, the State of Minnesota established daily water requirements based on the building occupancy as 38 L/person/day (the Revisor of Statutes, 2012). This is very close to the estimated international water consumption for swimming pools, between 37.85 L/person/day to 49.21 L/person/day (Wastewatergardens, 2000).

Water consumption in the swimming pools must be analyzed to quantify the water volume and identify unitary water consumption.

The swimming pool water consumption concerning total hotel water consumption is shown in Figure 3 - 34, which presents the data collected and analyzed from several studies (Rajini and Samarakoon, 2016; Smith et al., 2009; Gössling et al., 2012; US EPA, 2009; P. Paschke et al. 2002; Styles et al., 2013; Meade and Gonzalez-Morel 2011; Tang, 2012; Shiming, 2002). From all the studies, the resulting average contribution is 2.17%. This result is like the swimming pool consumption share within the total water consumption in American hotels, where swimming pool water contribution was 1% (Environmental Protection Agency, 2016). The remaining statistics are shown in the figure below.

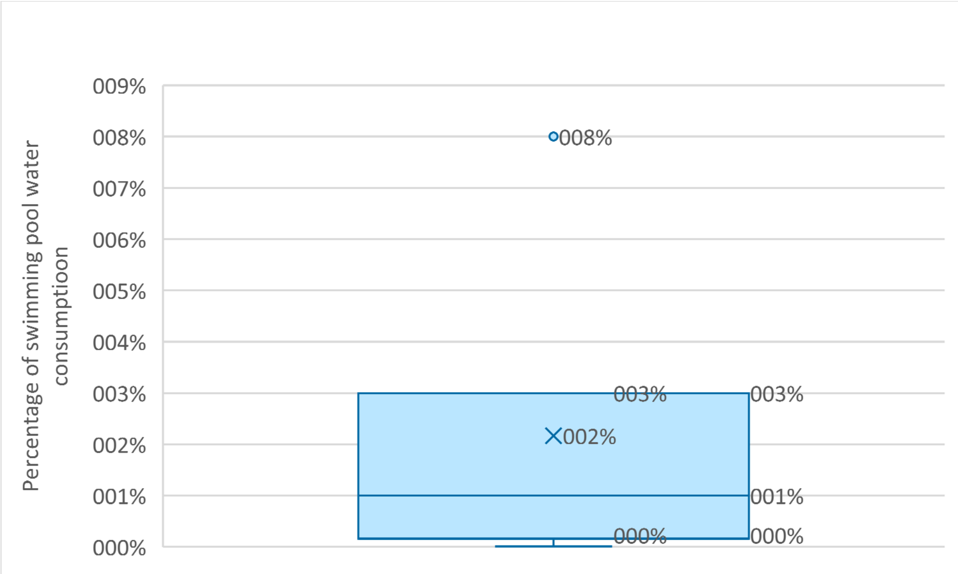


Figure 3 - 34 Swimming pool water consumption expressed as a percentage of total hotel water consumption

Besides, the average swimming pool water consumption (in L/d) is shown in Figure 3 - 35, which presents the data collected and analyzed from several studies (Tang, 2012; Paschke et al., 2002). From all the studies, the resulting average water consumed is 21,932 L/day. The remaining statistics are shown in the figure below.

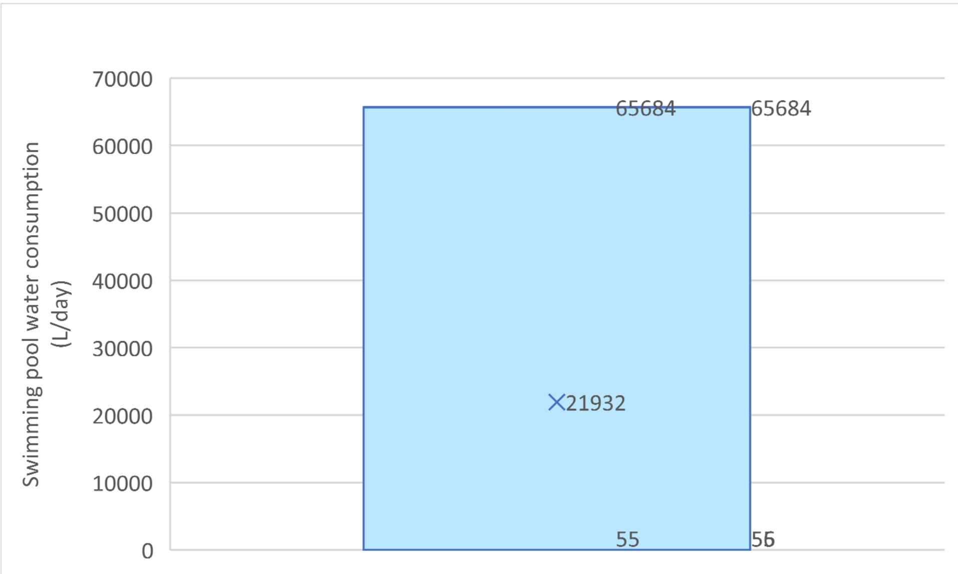


Figure 3 - 35 Daily swimming pool water consumption

We can calculate the average water consumption per swimmer, considering the number of swimmers in the swimming pool. Figure 3 - 36 presents the data collected and analyzed from several studies (Sterling forest resorts 2014; Comissão Europeia 2013; the Revisor of Statutes 2012; Wastewatergardens 2000). From all the studies, the resulting average consumption in the swimming pool is 44 L/swimmer/day. The remaining statistics are shown in the figure below.

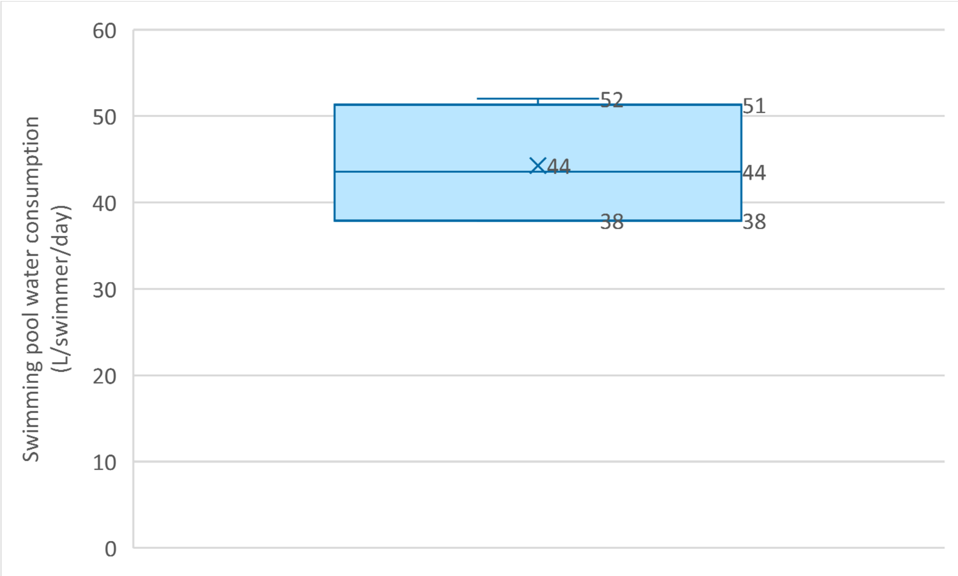


Figure 3 - 36 Swimming pool water consumption per swimmer

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of swimming pool water consumption is due to the following reasons:

- Paschke et al. (2002) pointed out that the swimming pool water is frequently drained, which causes a huge amount of water loss.
- Troy et al. (2005) indicated that rainfall and water evaporation influence water consumption in the swimming pool.
- Africa (2009) referred that a considerable amount of water consumption was due to backwashing of the pool filter, which has different efficiency factors.
- Styles et al. (2013) mentioned the ways of swimming pool maintenance and how often it is conducted, which affect water consumption in the swimming pools.
- Gracelinks (2013) estimated that around 126 L/day were lost in the swimming pool due to evaporation. This also depends on the location and the climate.

3.3.1.1.7 Other unaccounted and unintentional water consumption

Other water consumptions in the hotels include unaccounted and unintentional use, which also account for a significant volume of water, for example, public guest washrooms, staff toilets, cleaning, etc. (Gössling et al. 2011). It was estimated that the staff could consume about 16 L/day, mainly in toilet facilities. (CIRIA, 2006). In the Pittsburgh Omni hotel, other water use represented 4% of the total water consumption in the hotel. While in the Sheraton Suites Galleria, the yearly water consumption in different unintentional and unaccounted categories was estimated to be 7% of the total hotels' consumption (Resort, 2006).

Different definitions and approaches for calculating other water consumption lead to different results. The water efficiency in the commercial and institutional sectors in the WaterSense Program estimated that other consumption accounted for 12% of the total hotel consumption (US EPA, 2009). It was estimated 1% of the total water hotel usage in the New Mexico Office of the State Engineer (Environmental Protection Agency, 2016). Detailed studies on seven hotels in Denver, Phoenix, and Ventura indicate that other water consumption represents around 3% to 6% of water consumption in the hotel (Jane H. Ploeser et al.,1992).

Water consumption in other uses must be analyzed to quantify the water volume and identify unitary water consumption.

Without previous research on the other water consumption uses, developing a unitary water consumption is impossible. This analysis focuses on determining the total water consumption in other uses with respect to the total hotel water consumption. Consumption in other uses can be expressed as a percentage of total hotel water consumption (Figure 3 - 37, which is based on US EPA 2009; Resort 2006; Paschke et al., 2002; Styles et al., 2013; Smith et al., 2009; DPPEA 2009; Environmental Protection Agency 2016; Meade and Gonzalez-Morel 2011). From all these studies, the resulting average contribution is 12%. It is the same as the ones estimated in the New Mexico Office of the State (AWWA) and the East Bay Municipal Utility District. The remaining statistics are shown below.

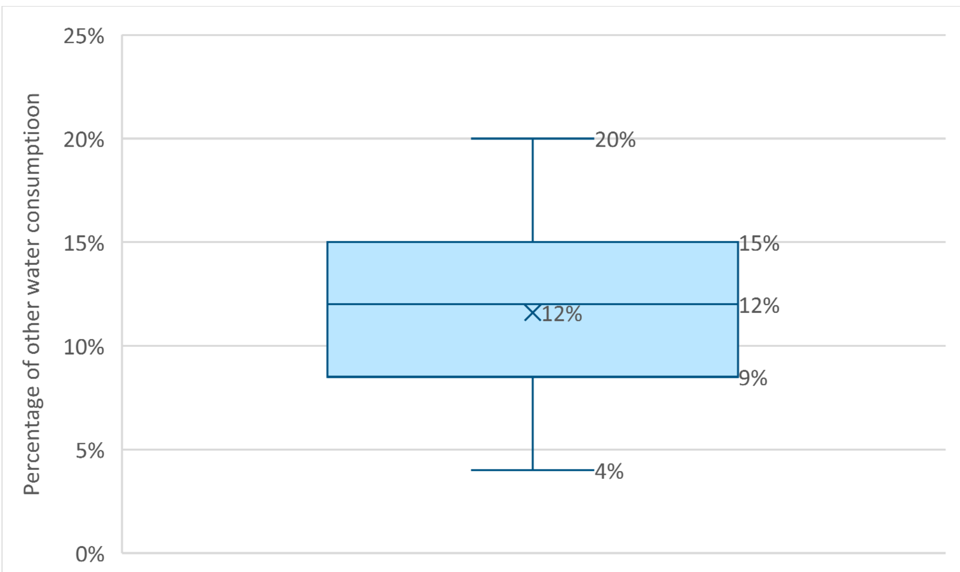


Figure 3 - 37 Other water consumption expressed as a percentage of total hotel water consumption

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of irrigation water consumption is due to the following reasons:

- Other water consumptions in the hotels include unaccounted and unintentional use, such as staff and public guest washrooms, staff quarters, cleaning, etc., that consume a considerable amount of water.

3.3.1.2 Hotel water consumption distribution analysis

This analysis aims to determine the amount of water consumption per floor area, guest, and room in the hotel. Based on the data collected and analyzed from several studies (Tang, 2012; Meade & Gonzalez-Morel, 2011; Shiming.D, 2002; Force, 2007; Joth and Francine,1999; Bohdanowicz & Martinac, 2007 and P. Paschke et al., 2002), the distribution of hotel water consumption is shown in Figure 3 - 38. From all the studies, the resulting average water consumed is 261,411 L/day. The remaining statistics are shown in the below figure.

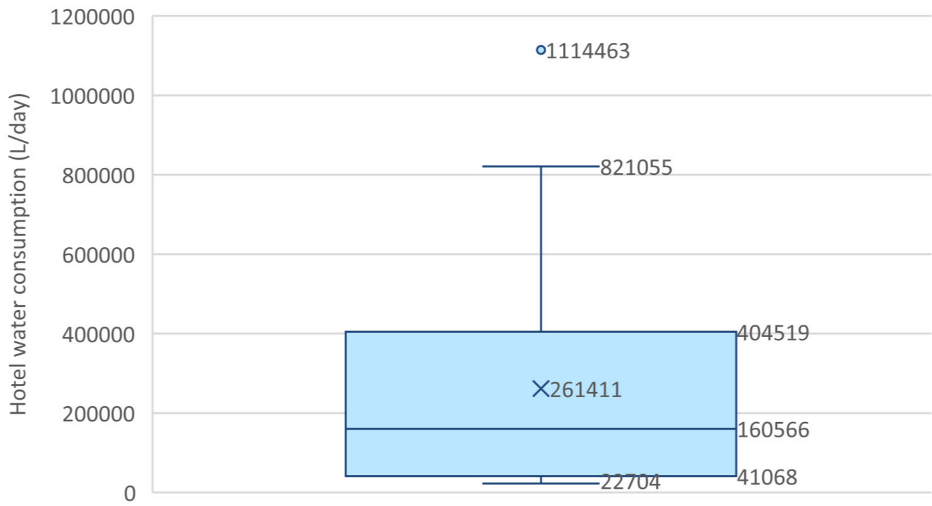


Figure 3 - 38 Distribution of daily water consumption in a hotel

3.3.1.2.1 Daily hotel water consumption distribution based on floor area

The distribution of hotel water consumption per floor area, considering the hotel's total floor area, is shown in Figure 3 - 39, which presents the data collected and analyzed from several studies (Tang, 2012 and Shiming.D, 2002). The resulting average is 6.89 L/m²/day. The remaining statistics are shown in the figure below.

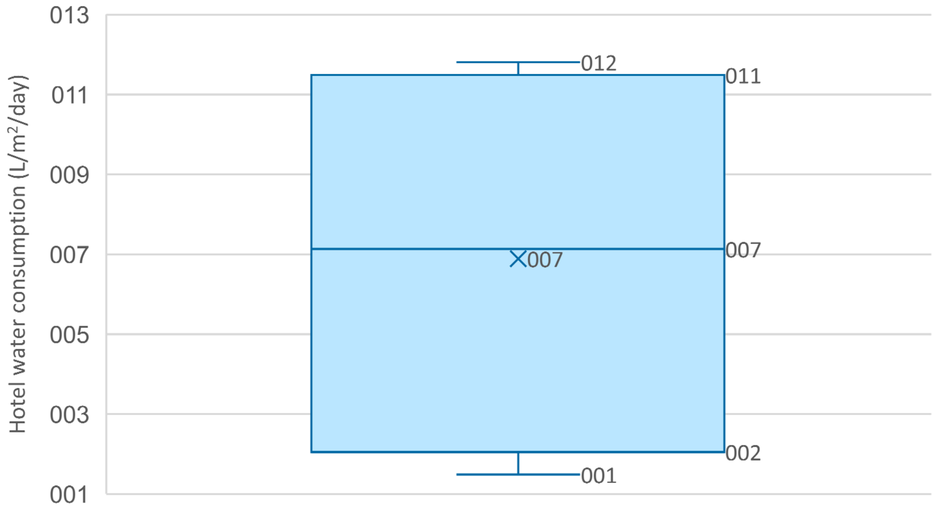


Figure 3 - 39 Distribution of daily per floor area water consumption in a hotel

Based on the data collected and analyzed from several studies (Tang, 2012 and Shiming.D, 2002), a variation in hotel water consumption with respect to the hotel's total floor area is shown in Figure 3 - 40. From all the studies, the highest value of water consumption per floor area was about 11.81 L/m²/day, and its hotel floor area is about 37,000 m². In contrast, the lowest water consumption value per floor area was about 1.49 L/m²/day, and its hotel floor area is about 43,835 m².

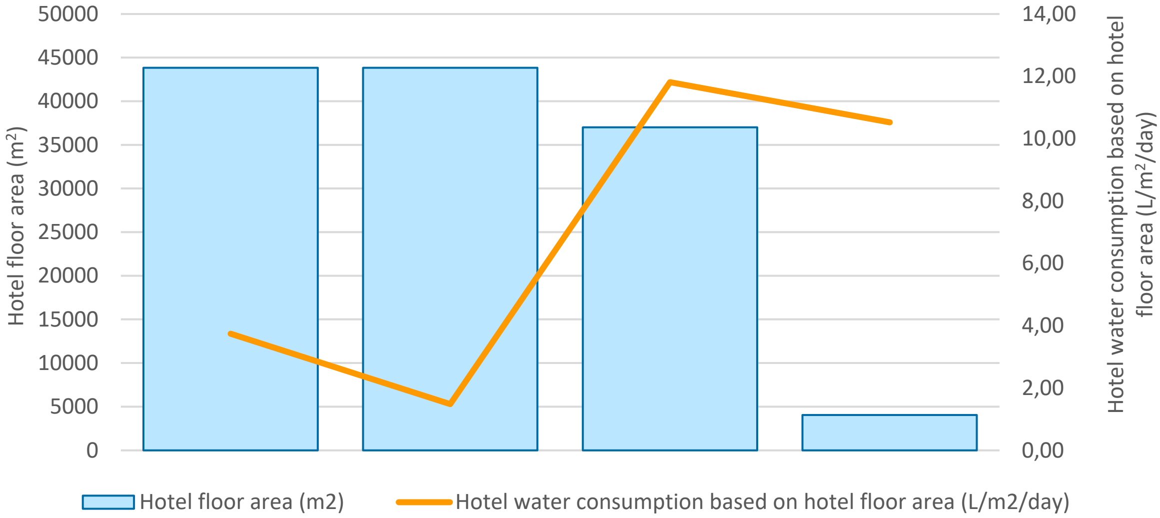


Figure 3 - 40 Hotel floor area vs daily water consumption in a hotel based on floor area

Based on the data collected and analyzed from several studies (Tang, 2012; Shiming, 2002), a plot of hotel water consumption and floor area, presented in Figure 3 - 41, indicates a negative correlation. It indicates a minimum water consumption threshold beyond which the per unit area water consumption decreases with an increase in the area.

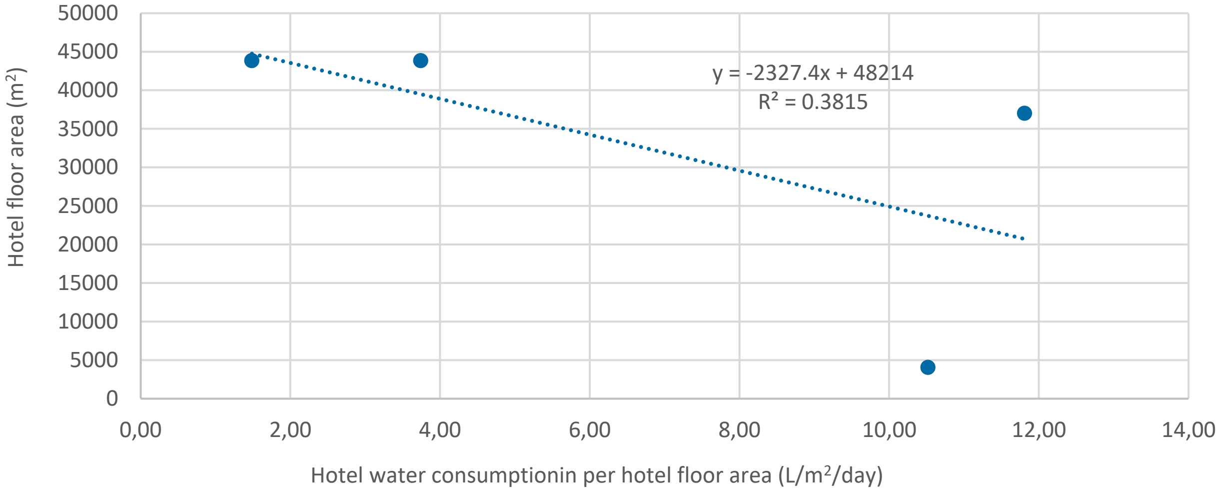


Figure 3 - 41 Correlation between hotel water consumption per floor area and hotel floor area

3.3.1.2.2 Daily hotel water consumption distribution based on the number of guests

The distribution of hotel water consumption per guest, considering the hotel's total guests, is shown in Figure 3 - 42, which presents the data collected and analyzed from several studies (Joth and Francine,1999; Tang, 2012; Bohdanowicz & Martinac, 2007). From all the studies, the resulting average is 686 L/guest/day. The remaining statistics are shown in the figure below.

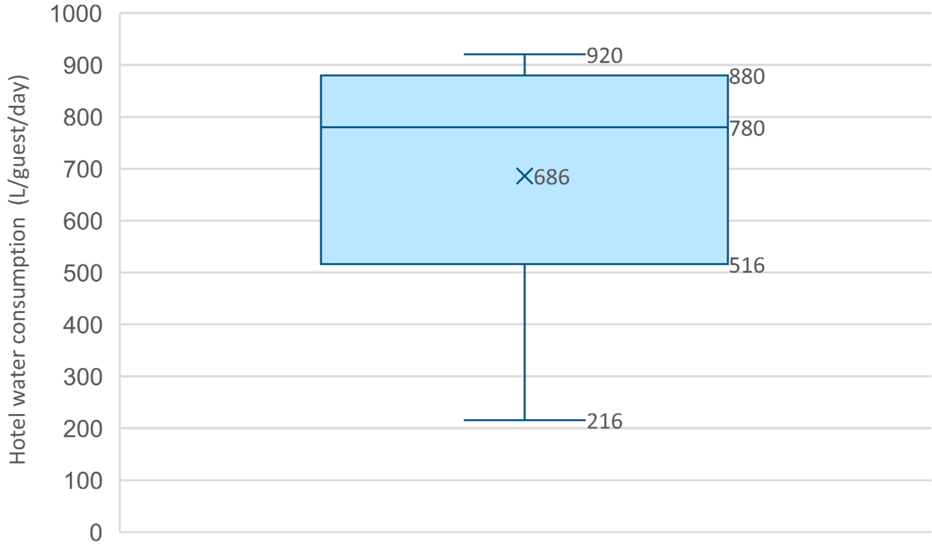


Figure 3 - 42 Distribution of daily per guest water consumption in a hotel

Based on the data collected and analyzed from several studies (Joth and Francine, 1999; Tang, 2012 and Bohdanowicz and Martinac, 2007), a variation of the hotel water consumption with respect to the hotel's guest number is shown in Figure 3 - 43. From all the studies, the highest value of hotel water consumption per guest was about 920 L/guest/day, and its hotel guest number is 360 guests. In contrast, the lowest value of hotel water consumption per guest was about 516 L/guest/day, and its number of guests was about 44 guests.

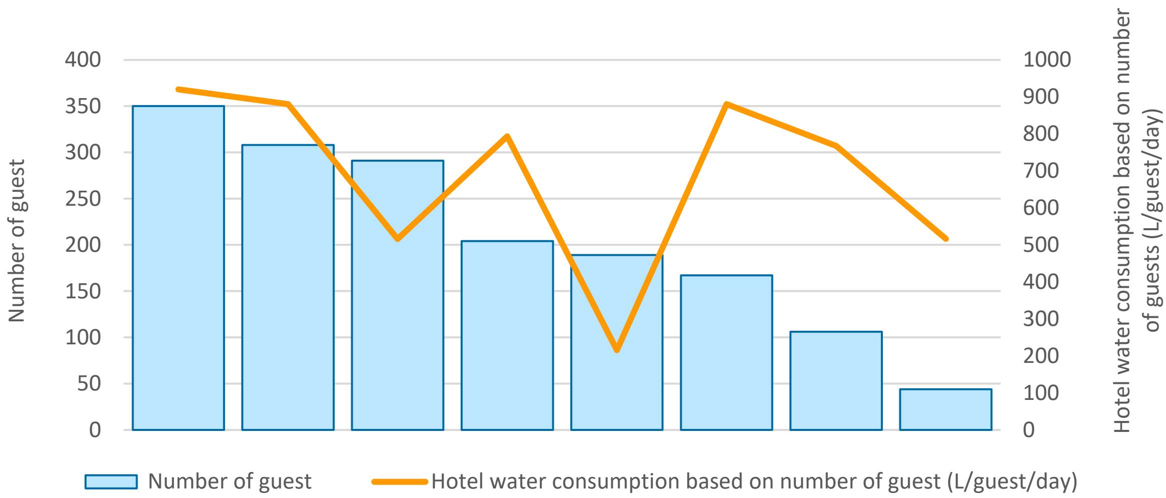


Figure 3 - 43 Number of guests vs hotel water consumption based on the number of guests

Based on the data collected and analyzed from several studies (Joth and Francine, 1999; Tang, 2012 and Bohdanowicz & Martinac, 2007), a plot of hotel water consumption and the number of guests presented in Figure 3 - 44 indicates a positive correlation between the two. It indicates a maximum water consumption threshold beyond which the per guest water consumption increases with an increased guests' number.

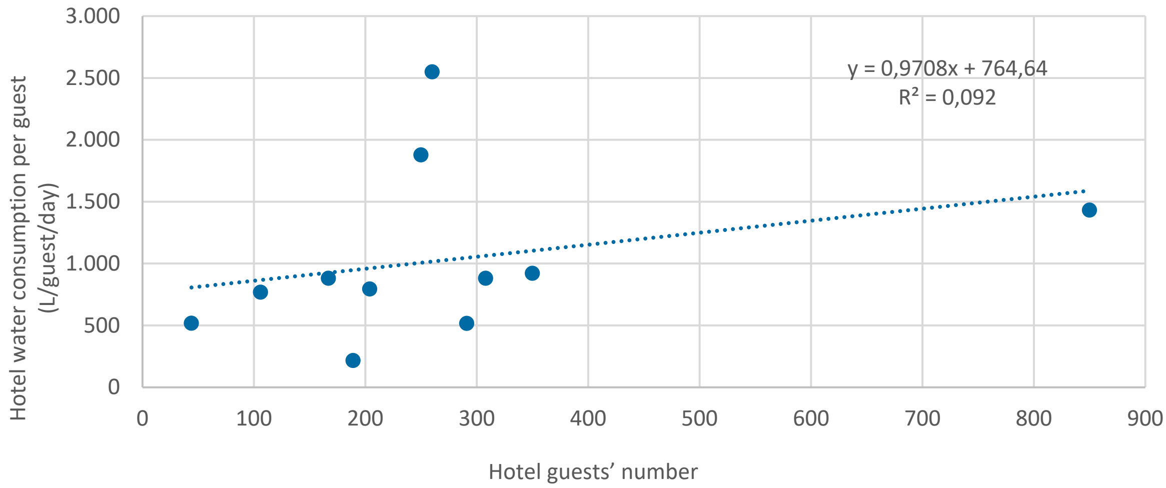


Figure 3 - 44 Correlation between hotel water consumption per guest and hotel guests' number

3.3.1.2.3 Daily hotel water consumption distribution based on the number of rooms

The distribution of hotel water consumption per room, considering the hotel's total rooms, is shown in Figure 3 - 45, which presents the data collected and analyzed from several studies (Tang, 2012; Meade & Gonzalez-Morel, 2011; Shiming.D, 2002; Force, 2007; Joth and Francine, 1999; Bohdanowicz & Martinac, 2007 and P. Paschke et al. 2002). From all the studies, the resulting average is 981 L/room/day. The remaining statistics are shown in the figure below.

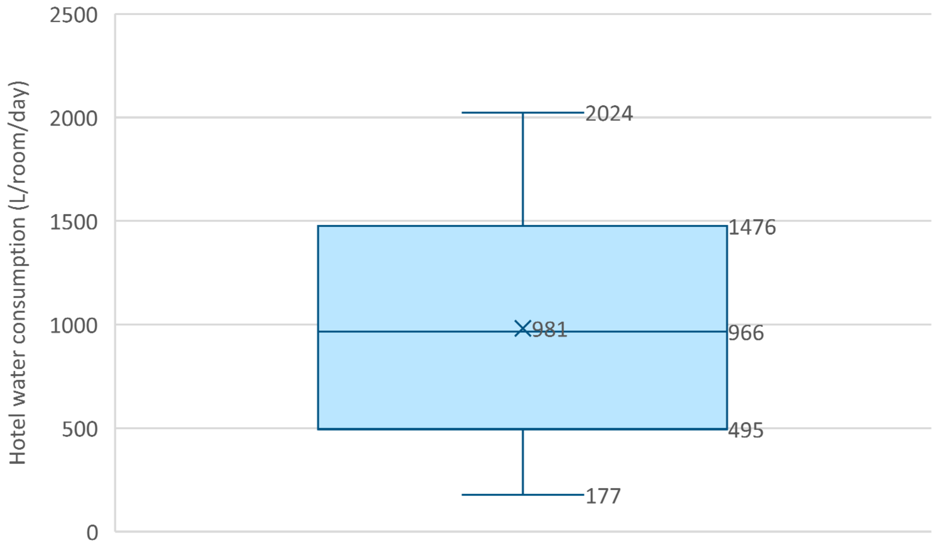


Figure 3 - 45 Distribution of daily per room water consumption in a hotel

Based on the data collected and analyzed from several studies (Tang, 2012; Meade & Gonzalez-Morel, 2011; Shiming.D, 2002; Force, 2007; Joth and Francine, 1999; Bohdanowicz & Martinac, 2007 and P. Paschke et al., 2002), a variation of hotel water consumption with respect to the number of rooms is shown in Figure 3 - 46. From all the studies, the highest value of hotel water consumption per room was about 1514 L/room/day, and its hotel rooms number is 2710. In contrast, the lowest value of hotel water consumption per room is about 424 L/room/day, and its hotel rooms number is 165 rooms.

Figure 3 - 43

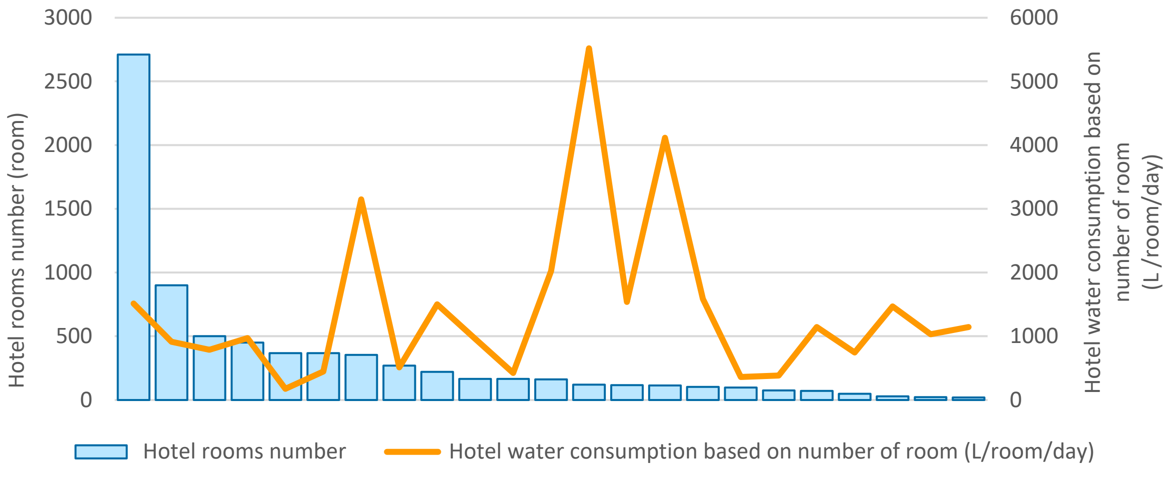


Figure 3 - 46 Hotel rooms number vs hotel water consumption based on the number of rooms

Based on the data collected and analyzed from several studies (Tang, 2012; Meade & Gonzalez-Morel, 2011; Shiming.D, 2002; Force, 2007; Joth and Francine, 1999; Bohdanowicz & Martinac, 2007 and P. Paschke et al., 2002), a plot of hotel water consumption and the number of rooms presented in Figure 3 - 47 indicates a negative correlation between the two. It indicates a minimum water consumption threshold beyond which the per room water consumption decreases with an increased rooms' number.

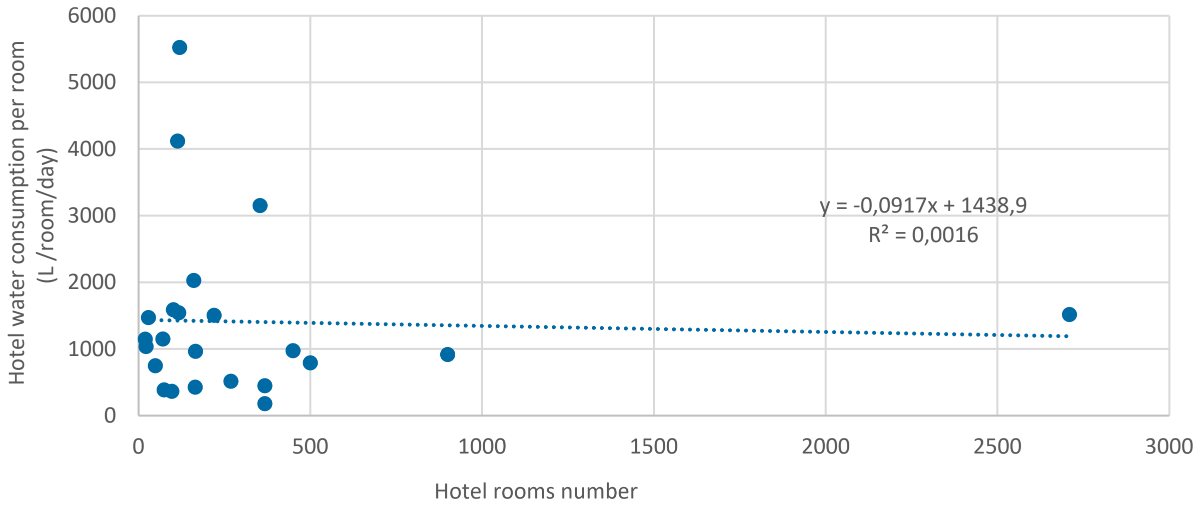


Figure 3 - 47 Correlation between hotel water consumption per room and hotel rooms number

3.3.1.3 Hotel water consumption findings

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of hotel water consumption is due to the following reasons:

- The Greater Vancouver Regional District (1998) pointed out that larger and older hotels consume a lot of water. So, older hotels consume more water than newer hotels.
- Paschke et al. (2002) mentioned a significant difference in water consumption among hotels. This is due to their ages, sizes, classes of the hotel, types of cooling, laundry, and kitchen facilities, which are shown to impact total water consumption significantly.
- Deng and Burnett (2002) described that hotel water consumption is affected by their main operational activities, for example, occupancy rate, housekeeping, maintenance, and the amount of food made in the kitchen.
- Bohdanowicz & Martinac (2007) and Vagiona & Mylopoulos (2004) explained that the intensive nature of services offered by hotels creates variations in water consumption.
- Meade & Gonzalez-Morel (2011) indicated that the hotel water consumption index changes yearly. This is due to the primary factors that affect the magnitude of the water consumption index, which are not limited to occupancy rate, irrigation, climate, guest types, and preventative maintenance practices.
- As Styles et al. (2013) explained, there are several reasons for variation in hotel water consumption, which include running the hotel, such as daily room cleaning, daily laundry, maintenance of swimming pools and irrigation. These activities vary from one hotel to another.

3.3.2 Restaurants water consumption

Restaurants are considered essential elements in the tourism sector as these contribute significantly to many countries' economies (Van Westering, 1999). Due to high water consumption, these have a significant environmental footprint (Petrevska et al. 2016). However, restaurants' water consumption represents a small part of municipal water consumption (Gleick et al.2004). Despite being a small fraction of municipal water consumption, restaurant water consumption represents a large volume of total water. For example, it was estimated in California that restaurant water was about 6% of total municipal water consumption (Gleick et al.2004).

Dziegielewski et al. (2000) stated that for each meal served in the restaurant, around 61 litres of fresh water are used; this is significant considering the number of restaurant customers in the United States exceeded 180.45 billion in 2010. Yet, insufficient research focuses on restaurant water usage (Alonso and Ogle, 2010; Revell and Blackburn, 2007; Alonso,2008). Hence there is a need to study water demand and consumption in restaurants to build benchmarks to help decrease water consumption. If water efficiency measures are implemented, restaurants could save up to 37% of water (Gleick et al. 2004).

Dziegielewski et al. (2000) stated that for each meal served in a restaurant, there are around 61 litres of fresh water used to prepare that meal; this figure is immense when mentioning the number of restaurant customers in the United States exceeded 180.45 billion in 2010. Yet, insufficient research and studies concentrate on restaurant water usage (Alonso,2008; Revell and Blackburn, 2007; Alonso and Ogle, 2010). So, there is an urgent need to study water demand and consumption in restaurants to build benchmarks to help decrease water consumption. If water efficiency methods and techniques are implemented, restaurants could save up to 37% of water consumption (Gleick et al. 2004).

Water benchmarking is extremely important in conserving water. Task Force of Colorado water providers performed quantitative research with the bottom-up approach to collect restaurant water consumption data. After analyzing the data, they concluded that the average water consumption in restaurants based on the number of seats was 110 L/seat/day to 149 L/seat/day. Based on the square meter space, it ranged from 19 L/m^2/day to 24 L/m^2/day (The Brendle Group, Inc., 2007). According to the water end-use study in the commercial and institutional sectors completed by the American Water Works Association Research Foundation, the best index of water consumption in restaurants is based on the number of seats. It ranged from 112 L/seat/day to 132 L/seat/day (Environmental & Series, 2007).

In 2009, the water division in Santa Fe held a yearlong study to analyze water consumption in restaurants. In that study, restaurants were classified into full-service and limited-service. The measured data were normalized by the maximum seating capacity. The study resulted in an average water consumption between 76 L/seat/day to 118 L/seat/day, equivalent to 23 L/meal/day and 34 L/meal/day as the upper value based on the number of meals (King et al., 2009).

In 2010, Colorado WaterWise and Aquacraft developed efficient water consumption benchmarking for restaurants. For accuracy, all the water providers in the state were included in the study. These water providers collected and analysed various restaurant water billings data using several metrics within one year. Several normalizing factors were obtained. The daily water consumption based on the number of meals was from 22.7 to 34.11 L/meal/day, while based on the number of seats was from 75.8 to 117.5 L/seat/day. In addition, if based on the building floor area (in square meters), it was from 15 to 37 L/m^2/day. Finally, if based on the number of employees, it was from 326 to 462 L/employee/day (Colorado WaterWise and Aquacraft Inc, 2010).

In a wide study implemented across 242 states in the USA, which included five companies to develop a profile of water consumption in restaurants from 2000 to 2012, it was found that the average water consumption in a restaurant based on the floor area was around 18 L/m^2/day (Edmunds & Associates, 2010).

It was noticed that ICI in Vancouver city consumed about 30% of city water resources. With the growing concern of increasing water consumption due to economic growth, the Engineering Department and Real Estate Department in Vancouver city adopted a project named “Restaurants and Microbreweries in the City of Vancouver” to obtain reliable data on the water use of restaurants. These data would help build a plan to decrease water use in the city by 2020. There were 152 restaurants included in this study. The study used both floor area and seating capacity as an index to normalize water consumption. The study concluded that the restaurant water consumption benchmark was based on the floor area and seating capacity as 29.1 L/m^2/day and 87.1 L/seat/day, respectively (Sirikan 2018).

3.3.2.1 Restaurant water consumption micro-components analysis

Restaurants' water consumption in the kitchen for food preparation, kitchen equipment and dishwashing, drinking, hygiene, and restroom use is the largest.

The United States Environmental Protection Agency (EPA) provides insight based on different sources' consumption data to understand the micro-components of restaurant water consumption. This breakdown includes 47% for the kitchen, 33% for restrooms,13% for other activities, including unaccounted and unintentional use, 5% for cooling and heating, and 2% for irrigation (gardens, etc.) (US EPA 2009).

The data analysis by the New Mexico Office of the State Engineer, American Water Works Association (AWWA), AWWA Research Foundation, and East Bay Municipal Utility District indicate the breakdown to be 52% for kitchens, 31% for restrooms, 12% for unaccounted and unintentional use, 5% for irrigation, and 2% for cooling and heating (Sirikan 2018).

Based on the data collected and analyzed from these different studies (US EPA 2009 and Sirikan 2018), the micro-components contribution to total restaurant water consumption is shown in Figure 3 - 48. As shown in the Figure, the average contribution was 50% for the kitchen, 32% for restrooms, 13% for other, including unaccounted and unintentional use, 5% for irrigation, and 2% for cooling heating.

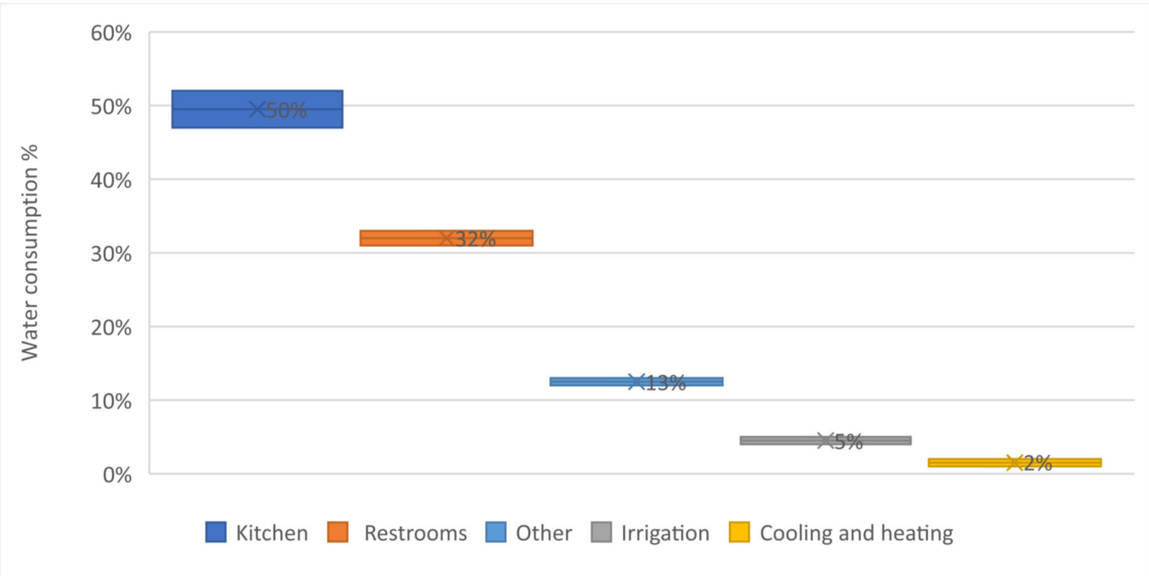


Figure 3 - 48 Analysis of water consumption micro-components in restaurants by use

3.3.2.2 Restaurants water consumption distribution analysis

This analysis aims to determine the amount of water consumption per floor area, customer, employee, seat, and meal in the restaurant. Based on the data collected and analyzed from several studies (Murakawa et al. 2004 and Kieger et al.2015), the distribution of restaurant water consumption is shown in Figure 3 - 49. From all the studies, the resulting average water consumed is 7,022 L/day. The remaining statistics are shown in the figure below.

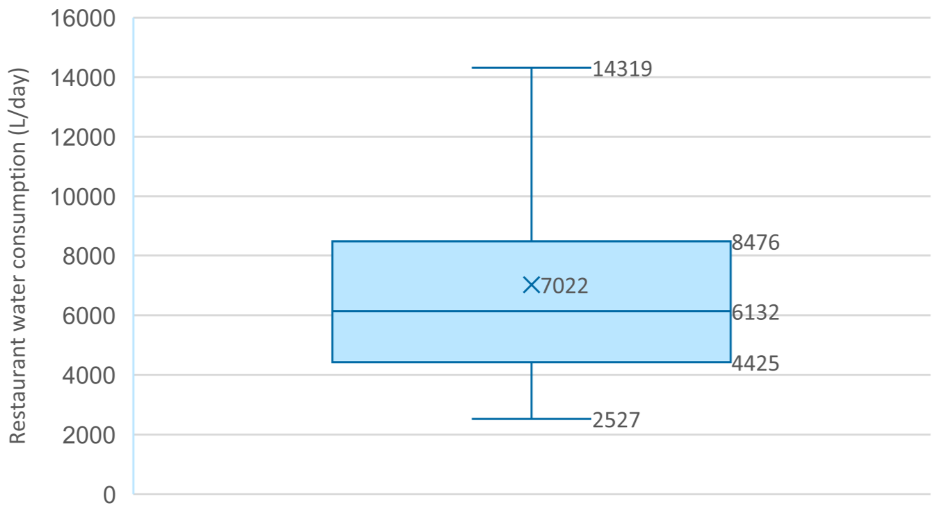


Figure 3 - 49 Distribution of daily water consumption in a restaurant

3.3.2.2.1 Daily restaurant water consumption distribution based on floor area

The distribution of restaurant water consumption per floor area, considering the restaurant's total floor area, is shown in Figure 3 - 50, which presents the data collected and analyzed from several studies (Murakawa et al.2004; Kieger et al. 2015; Jones Edmunds & Associates, 2010; Brendle Group, 2007; Sirikan, 2018; Environmental & Series, 2007; Colorado waterwise and aquacraft Inc, 2010; Force, 2007 and King et al., 2009). From all the studies, the resulting average is 30 L/m²/day. The remaining statistics are shown in the figure below.

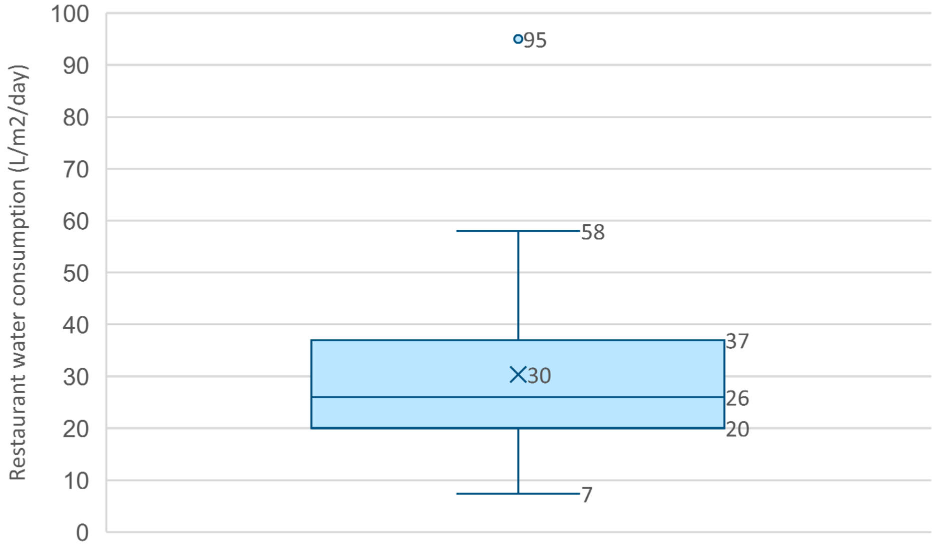


Figure 3 - 50. Distribution of daily per floor area water consumption in a restaurant

The average restaurant water consumption per floor area ranges from 20 - 37 L/m²/day. This range is relatively lower than the estimated 160 - 200 L/m²/day (Ohmsha,1995). Based on the data collected and analyzed from several studies (Murakawa et al. 2004 and Kieger et al. 2015), a variation in restaurant water consumption with respect to the restaurant's total floor area is shown in Figure 3 - 51 . From all the studies, the highest value of water consumption per floor area was about 95 L/m²/day, and its restaurant floor area was about 83 m². In contrast, the lowest value of water consumption per floor area was about 18 L/m²/day, and its restaurant floor area is about 782 m².

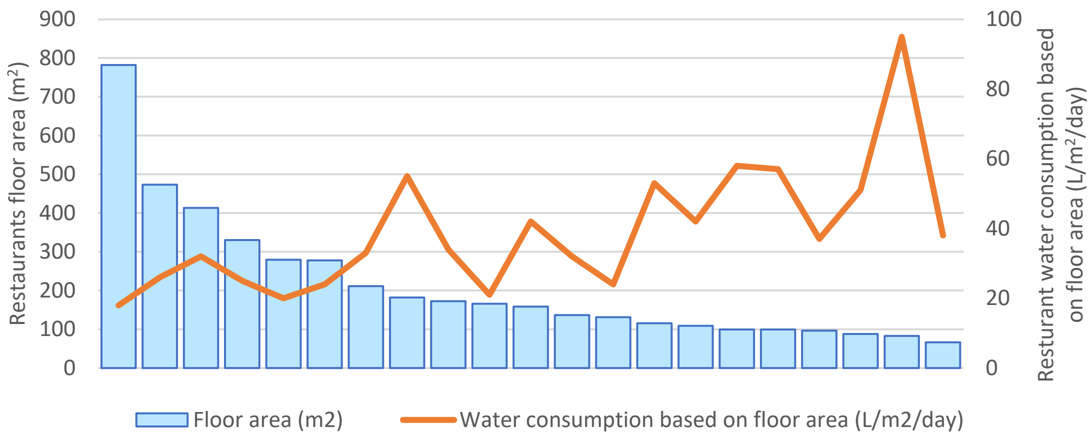


Figure 3 - 51. Restaurants' floor area vs daily water consumption in the restaurants based on floor area

Based on the data collected and analyzed from several studies (Murakawa et al. 2004 and Kieger et al. 2015), a plot of restaurant water consumption and floor area, presented in Figure 3 - 52, indicates a negative correlation between the two. It indicates a minimum water consumption threshold beyond which the per unit area water consumption decreases with an increase in the area.

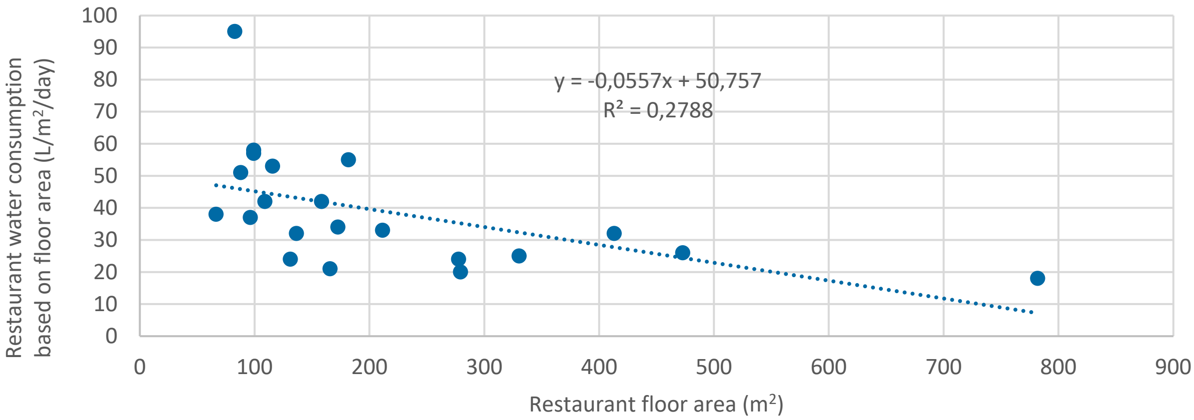


Figure 3 - 52 Correlation between restaurant water consumption per floor area and restaurant floor area

3.3.2.2.2 Daily restaurant water consumption distribution based on the number of customers

The distribution of restaurant water consumption per customer, considering the restaurant's customers, is shown in Figure 3 - 53, which presents the data collected and analyzed from several studies (Murakawa et al. 2004). From all the restaurants, the resulting average is 41 L/customer/day. The remaining statistics are shown in the figure below.

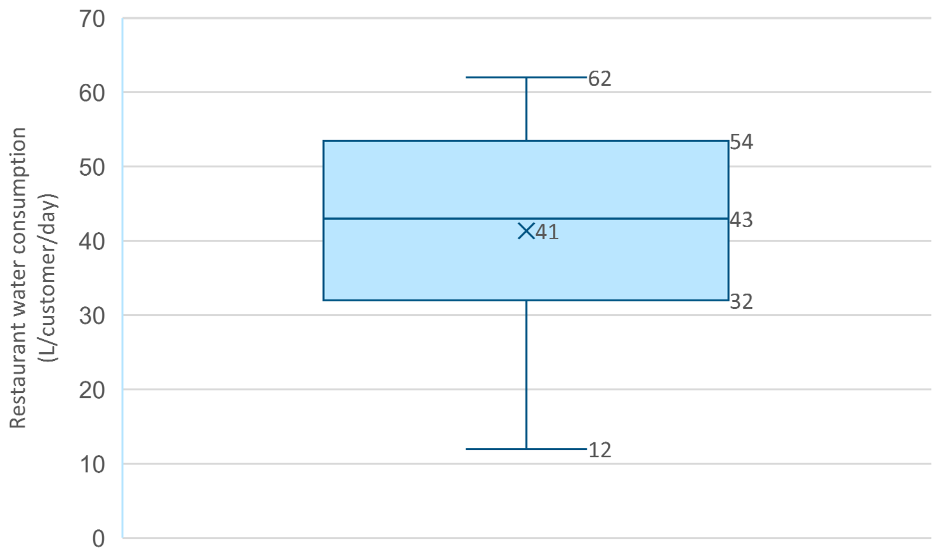


Figure 3 - 53 Distribution of daily per customer water consumption in the restaurant

The average restaurant water consumption per customer is in the range of 32 -54 L/customer/day. This range is relatively lower than the estimated 50- 60 L/customer/day (Ohmsha,1995). Based on the data collected and analyzed from several studies (Murakawa et al. 2004), a variation in restaurant water consumption with respect to the restaurant's customers is shown in Figure 3 - 43. Of all the restaurants, the highest value of water consumption per customer was about 62 L/customer/day, and its number of customers was 312 customers. In comparison, the lowest value of restaurant water consumption per customer was about 12 L/customer/day, and its number of customers was about 175 customers.

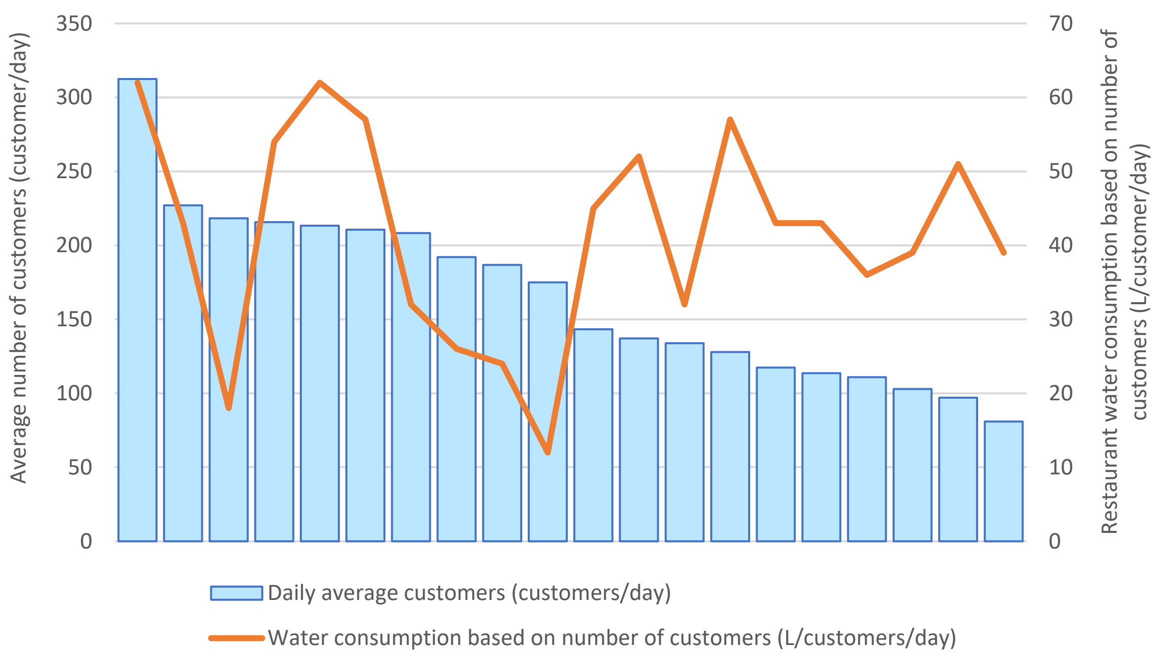


Figure 3 - 54 Number of customers vs restaurant water consumption based on the number of customers

Based on the data collected and analyzed from several studies (Murakawa et al. 2004), a plot of restaurant water consumption and the number of customers in Figure 3 - 55 indicates a positive correlation. It indicates a maximum water consumption threshold beyond which the per customer water consumption increases with an increased customers number.

Figure 3 - 55 Correlation between restaurant water consumption per customer and restaurant customers' number

3.3.2.2.3 Daily restaurant water consumption distribution based on the number of employees

The distribution of restaurant water consumption per employee, considering the restaurant's employees, is shown in Figure 3 - 56, which presents the data collected and analyzed from several studies (Murakawa et al. 2004; Kieger et al. 2015 and Colorado WaterWise and Aquacraft Inc, 2010). From all the studies, the resulting average is 485 L/employee/day. The remaining statistics are shown in the figure below.

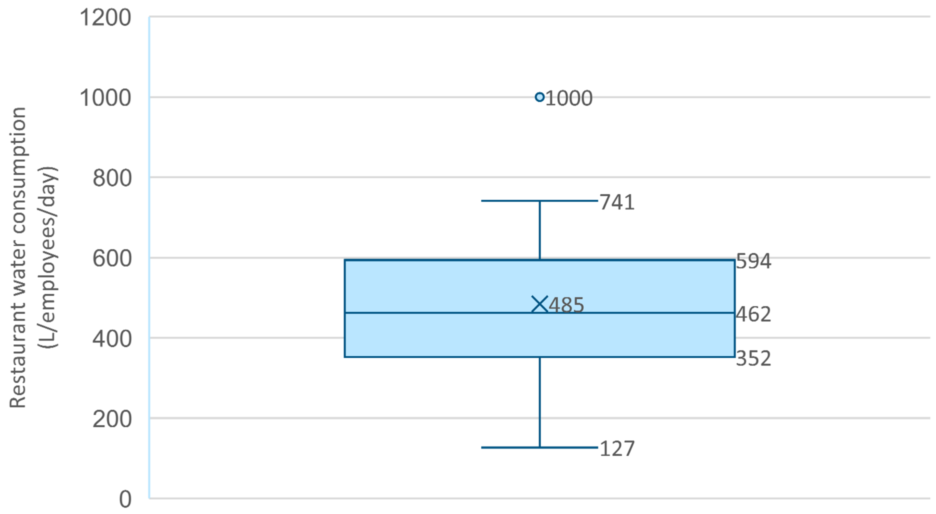


Figure 3 - 56 Distribution of daily per employee water consumption in the restaurant

The average resultant water consumption based on the number of employees is 352 - 594 L/employee/day. This range is relatively similar to the estimated 326 - 462 L/employee/day (Colorado WaterWise and Aquacraft Inc, 2010).

The research found no previous work relating to the number of employees in a restaurant with its total consumption. Therefore, when developing this thesis, it was impossible to derive how the per employee water consumption may change depending on the number of employees in a restaurant. In fact, none of the studies found included reliable data about the number of employees working in the restaurant.

Unfortunately, restaurants' water consumption with their number of employees is not available when developing the thesis. Consequently, the correlation between restaurant water consumption per employee and the number of employees cannot be visualized. So, this unitary water consumption needs to be further analyzed and investigated.

3.3.2.2.4 Daily restaurant water consumption distribution based on the number of seats

The distribution of restaurant water consumption per seat, considering the restaurant's seats, is shown in Figure 3 - 57, which presents the data collected and analyzed from several studies (Murakawa et al. 2004; Kieger et al. 2015; Jones Edmunds & Associates, 2010; Brendle Group, 2007; Sirikan, 2018 Environmental & Series, 2007; Force, 2007; Colorado waterwise and aquacraft Inc, 2010 and King et al., 2009). From all the studies, the resulting average is 158 L/seat/day. This average is relatively higher than the estimated 91 L/seat/day (Parks, 2012). It is lower than the estimated average water consumption index in the sterling forest resort master plan and hydraulic loading demand units drawn by the New York State Department of Environmental Conservation's (NYSDEC) Design Standards of 265 L/seat/day (Parks, 2012). The remaining statistics are shown in the figure below.

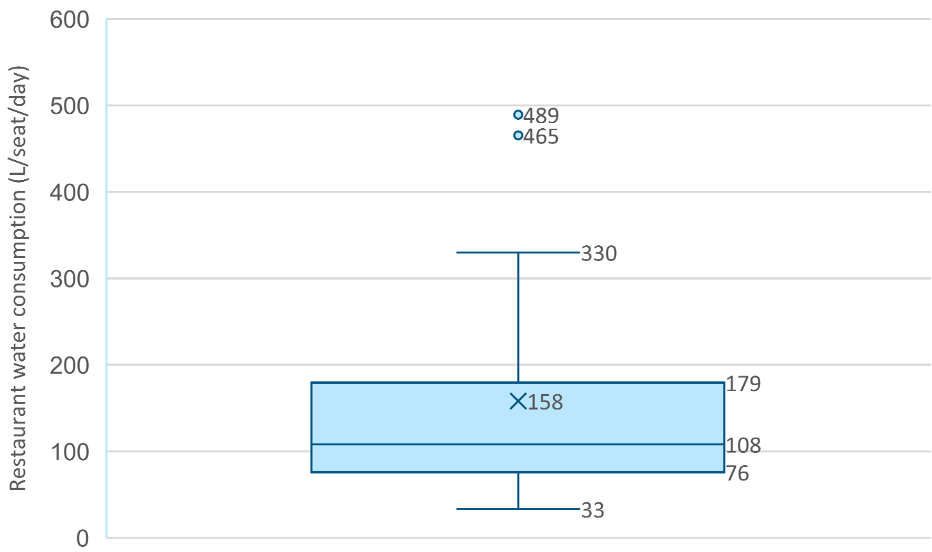


Figure 3 - 57. Distribution of daily per seat water consumption in a restaurant

Based on the number of seats, the average restaurant water consumption is 76 - 179 L/seat/day. This range is relatively higher than the estimated 76 – 117 L/seat/day benchmarks from the AWWA Commercial End Use study (Modified from Dziegielewski et al. 2000).

The research did not find any previous work relating the number of seats in a restaurant to their total consumption. Therefore, when developing this thesis, it was impossible to derive how the per seat water consumption may change depending on the number of seats in a restaurant. In fact, none of the studies found included reliable data about the number of seats working in the restaurant.

Unfortunately, restaurants' water consumption with their number of seats is not available when developing the thesis. Consequently, the correlation between restaurants' water consumption per set and the number of seats cannot be visualized. So, this unitary water consumption needs to be further analyzed and investigated.

3.3.2.2.5 Daily restaurants' water consumption distribution based on the number of meals

The distribution of restaurant water consumption per meal, considering the restaurant's meals number, is shown in Figure 3 - 58, which presents the data collected and analyzed from several studies (Kieger et al., 2015; Colorado WaterWise & Aquacraft Inc, 2010). From all the studies, the resulting average is 26 L/meal/day. The remaining statistics are shown in the figure below.

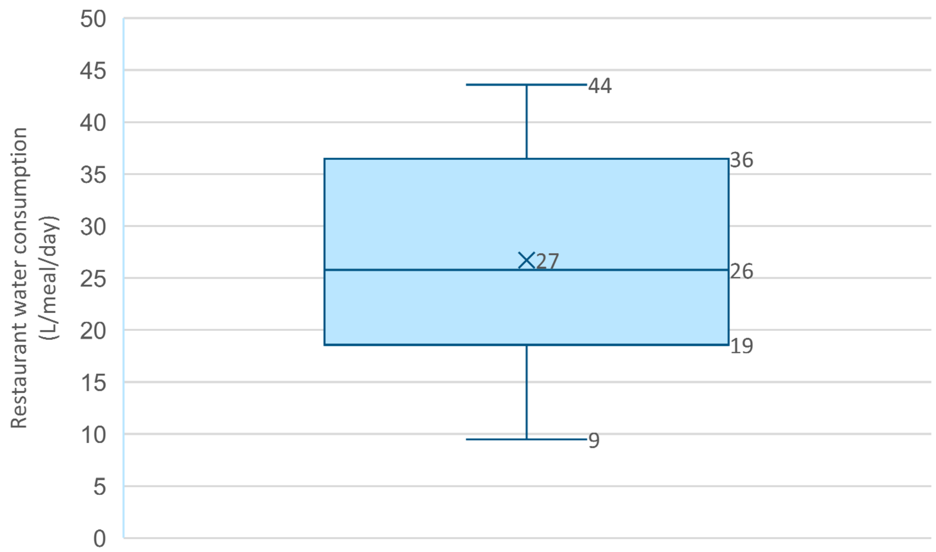


Figure 3 - 58. Distribution of daily per meal water consumption in the restaurant

The average restaurant water consumption per meal range is 19 - 36 L/meal/day. This range is similar to the estimated 23 – 34 L/meal/day benchmarks from the AWWA Commercial End Use study (Modified from Dziegielewski et al. 2000).

The research found no previous work on the number of meals in a restaurant with total water consumption. Therefore, when developing this thesis, it was impossible to derive how the per meal water consumption may change depending on the number of meals in a restaurant. In fact, none of the studies found included reliable data about the number of meals working in the restaurant.

Unfortunately, the mosque water consumption associated with the number of worshippers is not available when developing the thesis. Consequently, the correlation between mosque water consumption per worshipper and the number of worshippers cannot be visualized. So, this unitary water consumption needs further analysis and investigation.

3.3.2.3 Restaurant water consumption findings

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of restaurant water consumption is due to the following reasons:

- Dziegielewski et al. (2000) explained that Chinese restaurants consume a lot of water due to their work-station compared to other restaurants
- Vanschenkhof & Barrett (2000) indicated that employees' behaviour impacts water consumption.
- VanSchenkhof, (2011) illustrated that restaurants' water consumption varies with the menu types.
- Kieger et al. (2015) pointed out that restaurants differ in water consumption because some items in one restaurant and absent in others, such as hot water boilers, type of dishwashing system, and pre-rinse spray valves.
- Sirikan, (2018) indicated that the water consumption per seat index is widely varying since restaurants have different numbers of seats. Also, some restaurants operate more efficiently than others. As well, operating working hours might significantly affect water consumption in restaurants.

3.3.3 Cafe water consumption

In 2004, Polo estimated that the water consumption in his cafe was, on average, 340 L/day serving around 80 cars daily. If we assumed that the number of employees was about 1 to 2 employees per shop, the water consumption index per employee would be 170 L/employee/day to 350 L/employee/day (Coffeeforums, 2014).

In 2007, Sydney Water stated that the best water consumption index in a cafe is based on floor area and is estimated to be 2.48 L/m²/day (Sydney Water,2007).

In Spain, the micro-data of 352 cafes, which have operated in Zaragoza for over 12 years, showed that the average daily water consumption per cafe was 1,074 L/day with an average of seven employees. So, the average water consumption in restaurants based on the number of employees would be 147 L/employee/day (Cherry et al. 2014).

According to a forest resort master plan in the Sterling Forest resorts, the estimation of cafe water consumption based on the number of seats was 76 L/seat/day. This was calculated based on the hydraulic loading demand units outlined by the New York State Department of Environmental Conservation's (NYSDEC) design standards (Sterling Forest resorts, 2014).

A large international cafe retailer has focused on its water performance within its stores. It has committed to a 25% reduction in water use in its cafes by 2015. So far, the company has reported a decrease in store water consumption by 22%. Much of that decrease has resulted from discontinuing the use of dipper wells, fixtures that constantly stream water to clean utensils and eliminate food residues. Average water consumption based on the floor area in the U.S. and Canada company-owned stores dropped from 3.01 L/m²/day in the 2008 baseline to 2.3 L/m²/day in 2015. That enabled them to cut water consumption by around 378 litres of water per day per store (Starbucks, 2015).

In collaboration with the engineering and real estate departments, Vancouver conducted a water benchmarking study to understand typical water use better. Various water indications were developed as follows. The average benchmark result for cafes based on floor area was 17 L/m²/day, with the lower boundary at 13 L/m²/day and the upper limit at 21 L/m²/day. The average benchmark result based on seating capacity was 92 L/seat/day, with a softer edge of 46 L/seat/day and the upper boundary at 158 L/seat/day. The study also mentioned that the index obtained by the Pacific Institute for California, based on the number of employees, was 470 L/employee/day (Sirikan, 2018).

3.3.3.1 Cafe water consumption micro-components analysis

The research did not find any previous work relating to water consumption micro-components in cafes, so the information is not available when developing this thesis. For this reason, the best way to approach these components is through assumption and comparison.

In 2018, water benchmark consumption was studied in Vancouver for restaurants and microbreweries; it defined cafe water consumption under restaurant water consumption and considered the cafe as a restaurant category (Sirikan, 2018). So the cafe water consumption micro-component, as shown in Figure 3 - 59, could be assumed to be the same as the restaurant water consumption micro-component (Figure 3 - 48)), since both have similar functionality and the same micro-components.

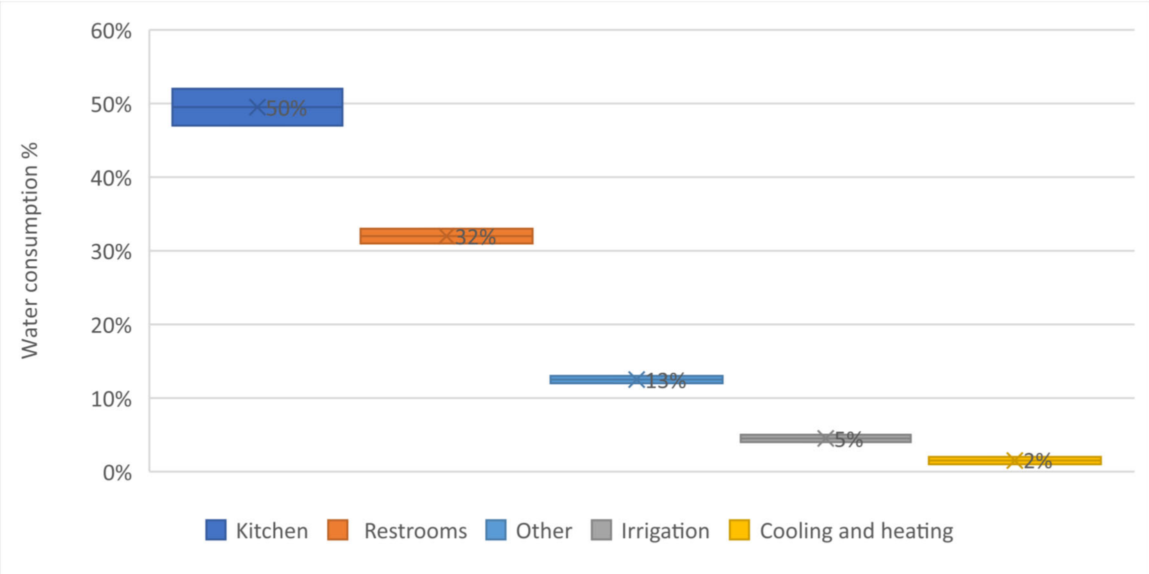


Figure 3 - 59 Analysis of water consumption micro-components in cafes by use

3.3.3.2 Cafe water consumption distribution analysis

This analysis aims to determine the amount of water consumption per floor area, employee, and seat in the cafe. Based on the data collected and analyzed from several studies (Cherry et al., 2014; coffeeforums, 2014), the distribution of cafe water consumption is shown in Figure 3 - 60. From all the studies, the resulting average water consumed is 707 L/day. The remaining statistics are shown in the figure below.

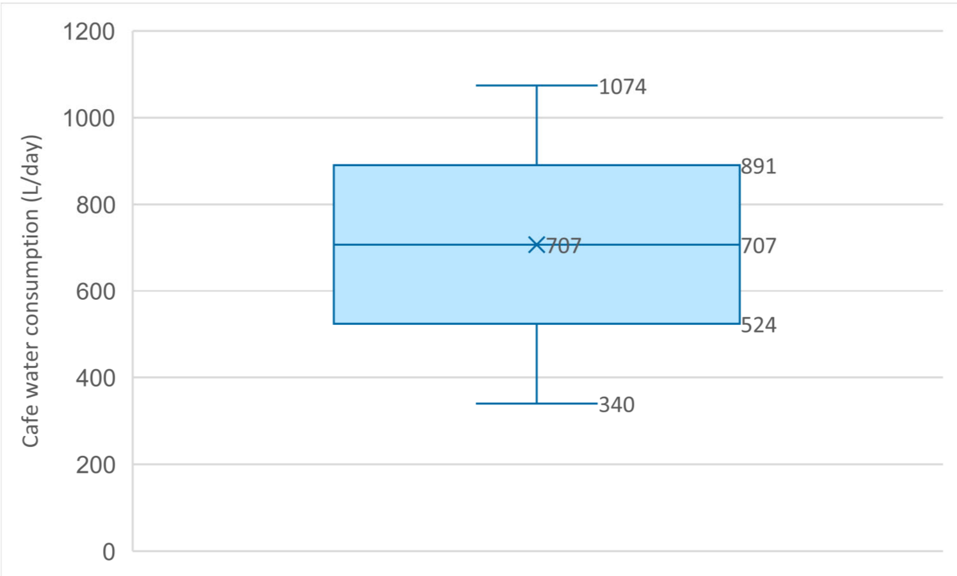


Figure 3 - 60 Distribution of daily water consumption in the cafe

3.3.3.2.1 Daily cafe water consumption distribution based on floor area

The distribution of cafe water consumption per floor area, considering the cafe's total floor area, is shown in Figure 3 - 61, which presents the data collected and analyzed from several studies (Cherry et al., 2014; coffeeforums, 2014; Sydney Water, 2007; Sterling forest resorts, 2014; Starbucks, 2015; Sirikan, 2018). From all the studies, the resulting average is 9.8 L/m²/day. The remaining statistics are shown in the figure below.

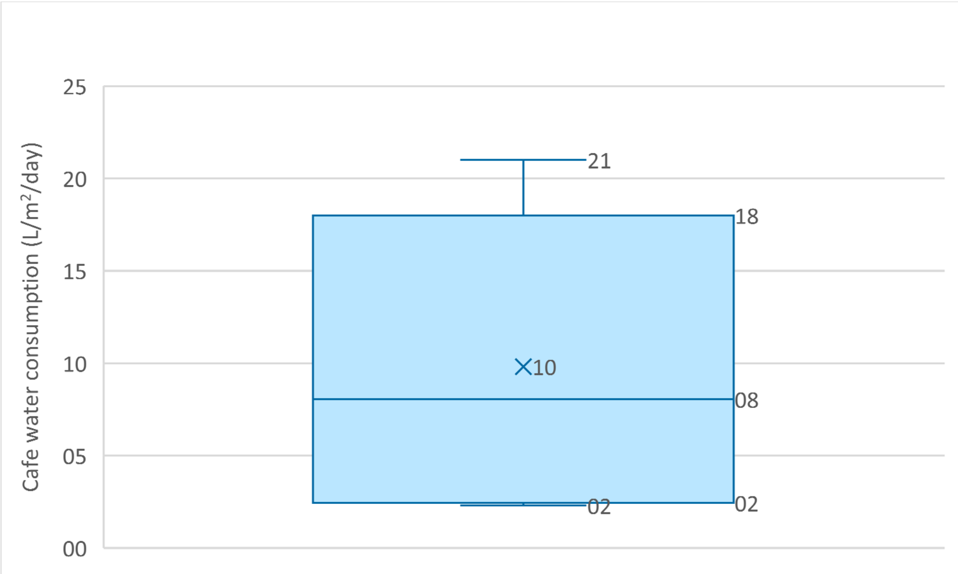


Figure 3 - 61 Distribution of daily water consumption in a cafe per floor area

The research found no previous work relating to the floor area in a cafe with its total consumption. Therefore, when developing this thesis, it was impossible to derive how the per floor area water consumption may change depending on the floor area in a cafe. In fact, none of the studies found included reliable data about the floor area in the cafe.

Unfortunately, cafes' water consumption per floor area is not available when developing the thesis. Consequently, the correlation between water consumption per floor area and cafes' floor area cannot be visualized. So, this unitary water consumption needs to be further analyzed and investigated.

3.3.3.2.2 Daily cafe water consumption distribution based on the number of employees

The distribution of cafe water consumption per employee, considering the cafe's employees number, is shown in Figure 3 - 62, which presents the data collected and analyzed from several studies (Cherry et al., 2014; coffeeforums, 2014; Sirikan, 2018). From all the studies, the resulting average is 282 L/employee/day. The remaining statistics are shown in the figure below.

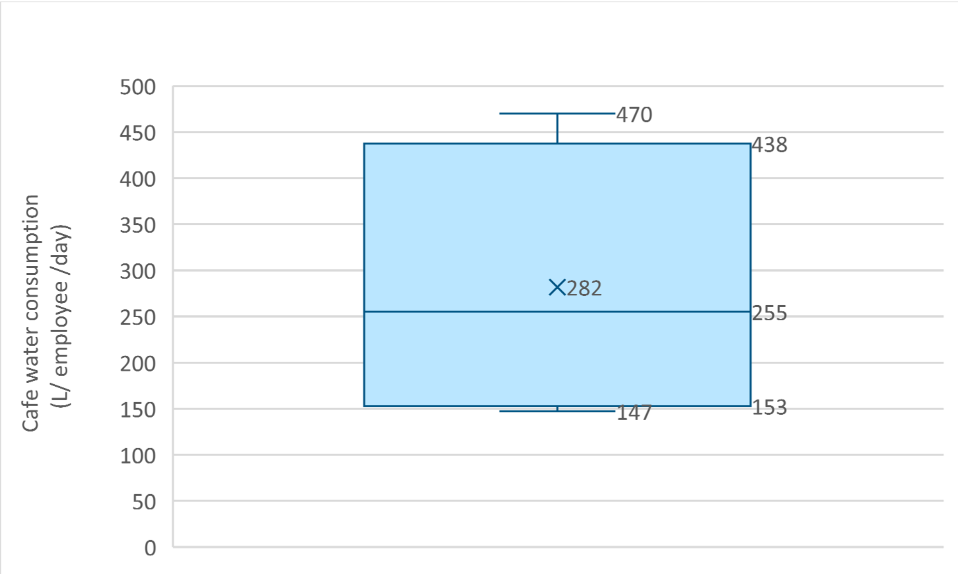


Figure 3 - 62 Distribution of daily water consumption in a cafe per employee

The research found no previous work relating to the number of employees in a cafe with its total consumption. Therefore, when developing this thesis, it was impossible to derive how the per employee water consumption may change depending on the number of employees in a cafe. In fact, none of the studies found included reliable data about the number of employees working in the cafe.

Unfortunately, cafes' water consumption with their number of employees is not available when developing the theses. Consequently, the correlation between cafe water consumption per employee and the number of employees cannot be visualized. So, this unitary water consumption needs to be further analyzed and investigated.

3.3.3.2.3 Daily cafe water consumption distribution based on the number of seats

The distribution of cafe water consumption per seat, considering the cafe's seats number, is shown in Figure 3 - 63, which presents the data collected and analyzed from several studies (Sterling forest resorts, 2014 and Sirikan, 2018). From all the studies, the resulting average is 79 L/seat/day. The remaining statistics are shown in the figure below.

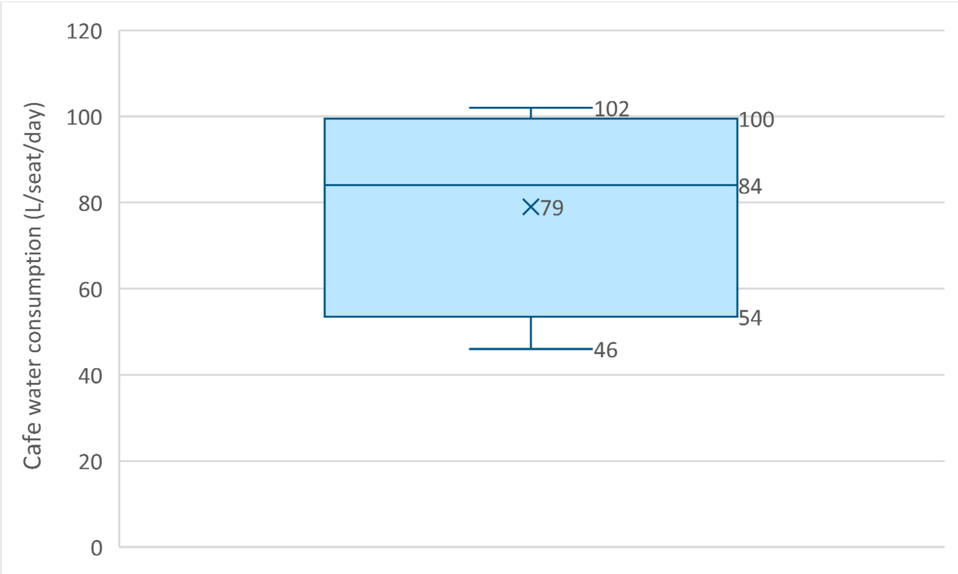


Figure 3 - 63 Distribution of daily per seat water consumption in a cafe

The research found no previous work relating to the number of seats in a cafe with their total consumption. Therefore, when developing this thesis, it was impossible to derive how the per seat water consumption may change depending on the number of seats in a cafe. In fact, none of the studies found included reliable data about the number of employees working in the cafe.

Unfortunately, cafes' water consumption with their number of seats is not available when developing the thesis. Consequently, the correlation between cafe water consumption is based on the number of seats, which cannot be visualized. So, this unitary water consumption needs to be further analyzed and investigated.

3.3.3.3 Cafe water consumption findings

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of cafe water consumption is due to the following reasons:

- Starbucks (2015) cafes differ from other cafes because of the quantities of water they consume due to differences in their operational capacity, practices, methods of use, and rationing.
- Statista Research Department (2015) showed that 32% of the cafes used tap water while the rest used bottled water. That means that a significant amount of bottled water is used, which is sometimes not recognized.

3.3.4 Office water consumption

Globally, only a few studies have been conducted on the consumption of water in office buildings (Bint et al., 2000; Bannister et al., 2005).

In 2000, New Zealand had no available information on how office buildings consume water (Bint et al. 2000). As a result, research developed in New Zealand then studied 44 elected office buildings to anticipate and establish a benchmark in office buildings. The estimated office building water consumption was 3.21 L/m^2/day (Bint et al. 2000).

American Water Works Association (AWWA) considers office building consumption in 2.9 - 3.9 L/m^2/day (Dziegielewski et al. 2000).

In Australia, across 132 office buildings and 18 public buildings, water consumption data and characteristic was collected to detect technical and operational characteristics of the office buildings, and water consumption intensity in litre per square meter was developed. It is suggested that a generic benchmark for average water consumption of office buildings as 9.15 L/m^2/day for average floor area as 13312 m^2 and a best practice benchmark as 5.48 L/m^2/day have been recognized based on the data collected (Bannister et al. 2005).

The UK Watermark program identified a water consumption benchmark of 25 L/employee/day and a best practice of 18 L/employee/day. Interpreted at an occupant density of 1 per 18 m^2 these figures become 1.42 L/m^2/day and 0.97 L/m^2/day respectively, while in New Zealand, these figures normalize to 2.96 L/m^2/day and 2.52 L/m^2/day respectively (Bannister et al. 2005).

To compare different office building water consumption, it needs to be turned into a standard factor. This can be completed based on the number of employees or floor area (per square meter). The preferable factor will depend on the type of business. If the number of employees in the office looks very variable (such as a variable number of employees over the years staff), you may get it better to use a floor area factor. Nevertheless, if employees are based mainly at the office, or the office has few employees for the space you occupy (such as a small office inside a larger warehouse), it would be better to use the number of employees factor (Waggett and Arotsky, 2006).

The main factor determining total water consumption in an office building is expected to be the number of employees working there (Waggett and Arotsky, 2006).

In 2006, a study was conducted across England and Wales offices. To develop suitable benchmarks for water consumption in an office building that will enable designers to target usage (Wagett and Arotsky, 2006). Data findings and analysis show that office building water consumption based on the number of employees is estimated as 15.8 L/employee/day and based on floor area as 2.4 L/m^2/day. In contrast, the best practice recommends 7.9 L/employee/day and 1.6 L/m^2/day for upstream consumption as 27.7 L/employee/day and 3.2 L/m^2/day (Wagett and Arotsky, 2006).

A significant quantity of water is consumed in office buildings, estimated as 10% of a city's water consumption levels (BIS and Cranfield University, 2009). An office building that measures 10000 m^2 normally consumes more than 20000 L/day, corresponding to 2 2 L/m^2/day (BIS and Cranfield University, 2009).

In 2009, the water division of the City of Santa Fe analyzed water use and developed a study of residential and commercial water uses in the Santa Fe Urban area. The findings were compared to a 1998 study to determine the potential impact conservation measures may have had on water use by different types of users in Santa Fe. In 1998, offices were classified as either having landscaping or without landscaping, and these were primarily government offices with approximated consumption rates of 2.53 (L/m^2/day). While in a 2008 study, this classification was removed and was expanded to cover governmental and non-governmental offices with approximated consumption rates of 2.12 L/m^2/day (King et al., 2009).

Based on the practice and custom of the Miami-Dade County Water and Sewer Department, municipal water and wastewater flow demand in office buildings is estimated to be 4.1 L/m^2/day (Countyline, 2008). In contrast, the St. Johns River Water Management District's (District) contracted estimate, considered the average office building benchmark, equates to 1.79 L/m^2/day (Jones Edmunds & associates 2010).

Consumption in office buildings is like that in schools. Both are open during working hours, consume water in restrooms and are frequently for municipal use (Farina et al. 2011).

2012 saw the development of the end-use water project in Malta's Business Bureau. This project demonstrated water consumption benchmarks for several industries of different classifications and got office building water consumption of 25 L/employee/day (Marco CremonaSaliba, 2012). In contrast, water efficiency in the commercial and institutional sector for the WaterSense Program estimated office building water consumption as 12.5 L/employee/day (US EPA, 2009).

In the State of Minnesota, the minimum water consumption in office buildings was estimated as 57 L/employee/day (the Revisor of Statutes, 2012).

3.3.4.1 Office water consumption micro-components analysis

Office buildings typically consume water in three major areas: restrooms, cooling and heating, and landscaping and may include a kitchen (New Mexico Office of the State Engineer, 1999).

The data analyzed by the New Mexico Office of the State Engineer stated in the water conservation guide for commercial, institutional, and industrial users indicate the office water consumption micro-components to be 40% for restrooms, 22% for irrigation, 28% for cooling and heating, 9% for other consumptions which include unaccounted and unintentional use and 5% for the kitchen (Resort, 2006).

In 2008, East Bay Municipal Utility District issued a Watersmart Guidebook, which contains characteristics of water consumption breakdown in the office as follows: 34% in the restrooms; 28% for the cooling and heating; 27% for the irrigation (gardens, etc.); and 11% in the kitchen (Jones Edmunds & Associates, 2010).

In Australia, Quinn R et al. (2009) conducted an audit of office water consumption and illustrated that distributed as follows; 37% in the restrooms, 31% for the cooling and heating, 26% for leakage, 3% in the kitchen, 2% on other uses which include unaccounted and unintentional use, and 1% for irrigation.

To understand the water consumption breakdown in the offices, the United States Environmental Protection Agency (EPA) provides some insight based on the consumption data from different sources. This breakdown includes 37% for restrooms, 28% for cooling and heating, 22% for irrigation (gardens, etc.), and 13% for the kitchen (US EPA, 2009).

In the USA, Albrecht et al. (2009) showed that according to the information presented in their study, the water consumption breakdown in the office is as follows: approximately 40% for restrooms, 28% for cooling and heating, 22% for irrigation, 9% on other uses which include unaccounted and unintentional use, and 1% for kitchen.

Different results were obtained from “Guideline for baseline water use determination and target sitting in the commercial sector” (Africa, 2009), where office water consumption was associated as the following; 45% in restrooms, 35% for the cooling and heating; 10% for leakage; 6% for irrigation; 3% in the kitchen and 1% for cleaning.

In Malta, Cremona and Saliba (2012) conducted an audit of office water consumption and found that distributed as follows; 81% for restrooms; 13% for washing basins, 4% for kitchens and 2% for cleaning.

Based on the data collected and analyzed from these different studies (Albrecht et al., 2009; US EPA, 2009; Cremona & Saliba, 2012; Resort, 2006; Jones Edmunds & Associates, 2010; Quinn R et al., 2006), the contribution of water consumption micro-components with respect of total office water consumption is shown in Figure 3 - 64. The figure below shows that the average contribution was 38% for restrooms, 19% for irrigation, 28% for cooling and heating, 6% for kitchen, and 6% for other, including unaccounted and unintentional use.

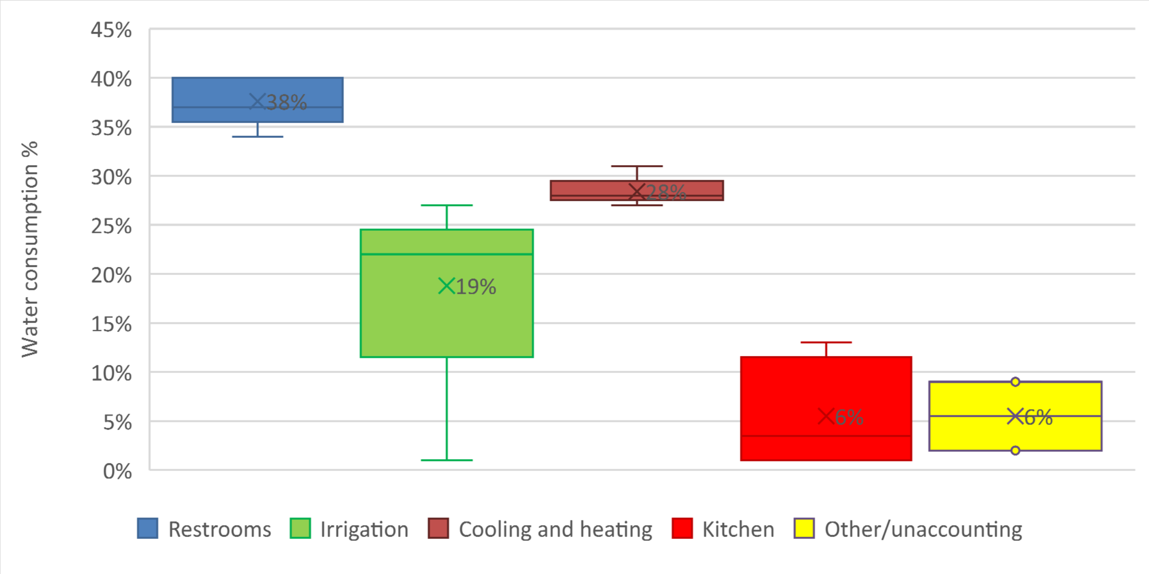


Figure 3 - 64 Analysis of water consumption micro-components in offices by use

3.3.4.2 Office water consumption distribution analysis

This analysis aims to determine the amount of water consumption per floor area and employee in the office. Based on the data collected and analyzed from several studies (BIS and Cranfield University, 2009; Kieger et al., 2015; Jones edmunds and associates, 2010), the distribution of office water consumption is shown in Figure 3 - 65. From all the studies, the resulting average water consumed is 17,448 L/day. The remaining statistics are shown in the figure below.

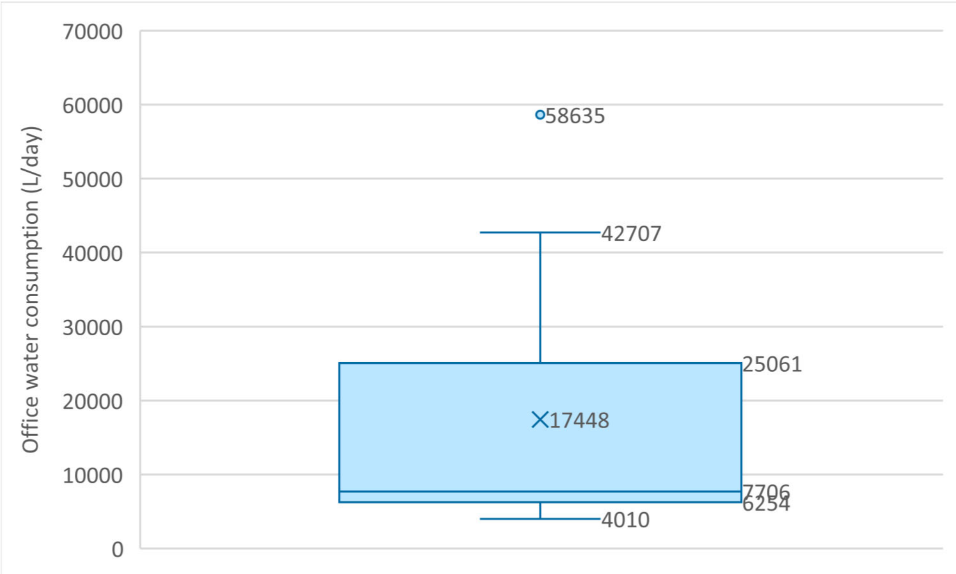


Figure 3 - 65 Distribution of daily water consumption in an office

3.3.4.2.1 Daily office water consumption distribution based on floor area

The distribution of office water consumption per floor area, considering the office's total floor area, is shown in Figure 3 - 61. It presents the data collected and analyzed from several studies (Bint et al., 2000; Bannister et al., 2005; Wagett and Arotsky, 2006; Countyline, 2008; Jones Edmunds & associates, 2010; King et al., 2009; US EPA, 2009; Dziegielewski et al. 2000; Marco Cremona Saliba, 2012; the Revisor of Statutes, 2012). From all the studies, the resulting average is 2.89 L/m²/day. The remaining statistics are shown in the figure below.

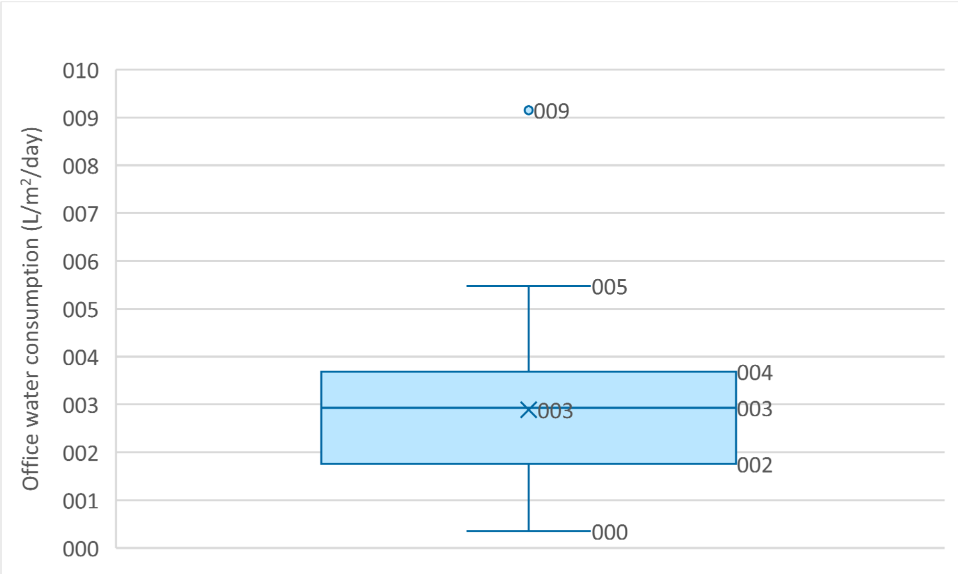


Figure 3 - 66 Distribution of daily per floor area water consumption in office

Based on the data collected and analyzed from several studies (BIS and Cranfield University, 2009; Kieger et al., 2015 and Jones edmunds and associates, 2010), a variation of office water consumption with respect to the office's total floor area is shown in Figure 3 - 67. From all the studies, the highest value of water consumption per floor area was about 13 L/m²/day, and its office floor area was about 25,453 m². In contrast, the lowest water consumption value per floor area was about 1.5 L/m²/day, and its office floor area is about 558 m².

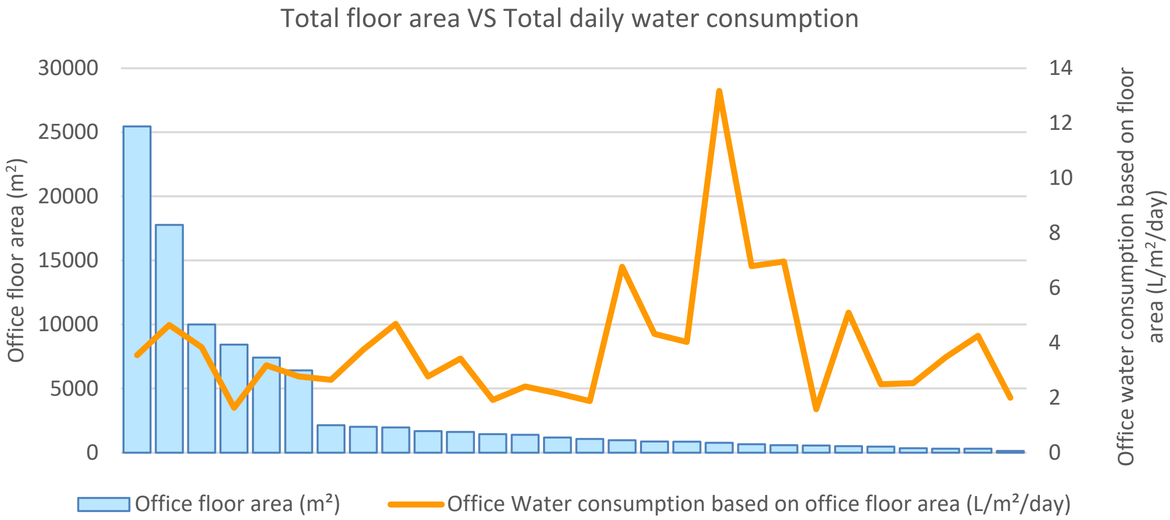


Figure 3 - 67 Office floor area vs daily water consumption in office based on floor area

Based on the data collected and analyzed from several studies (Jones edmunds & associates 2010), a plot of office water consumption and floor area presented in Figure 3 - 68 indicates a positive correlation. It indicates a maximum water consumption threshold beyond which the per unit area water consumption increase with an increase in the area.

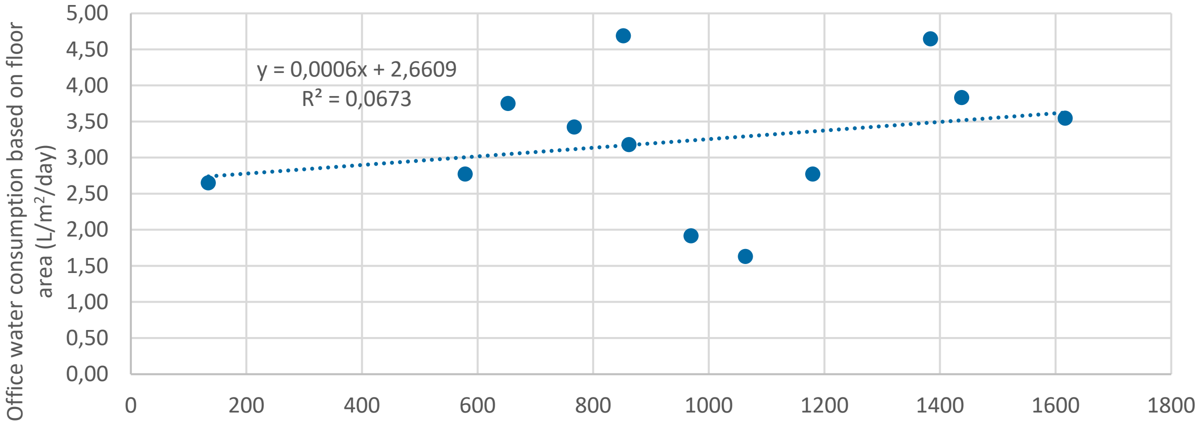


Figure 3 - 68 Correlation between offices' water consumption per floor area and floor area

3.3.4.2.2 Daily office water consumption distribution based on the number of employees

The distribution of office water consumption per employee, considering the office's employees number, is shown in Figure 3 - 69, which presents the data collected and analyzed from several studies (Bannister et al. 2005; Wagett and Arotsky, 2006; US EPA, 2009; Marco Cremona Saliba, 2012; the Revisor of Statutes, 2012). From all the studies, the resulting average is 29.12 L/employee/day. The remaining statistics are shown in the figure below.

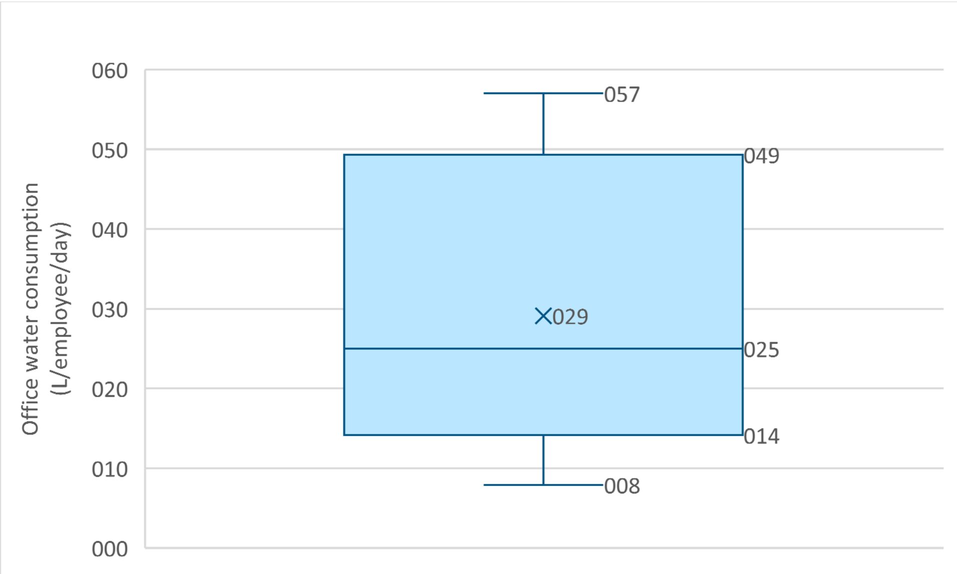


Figure 3 - 69 Distribution of daily per employee water consumption

Based on the data collected and analyzed from several studies (Kieger et al. 2015), a variation in office water consumption with respect to the number of employees is shown in Figure 3 - *70*. From all the studies, the highest value of water consumption per employee was about 2539 L/employee/day, and its number of employees was about 670 employees. The lowest water consumption value per employee was about 19 L/employee/day, and its number was about 5 employees.

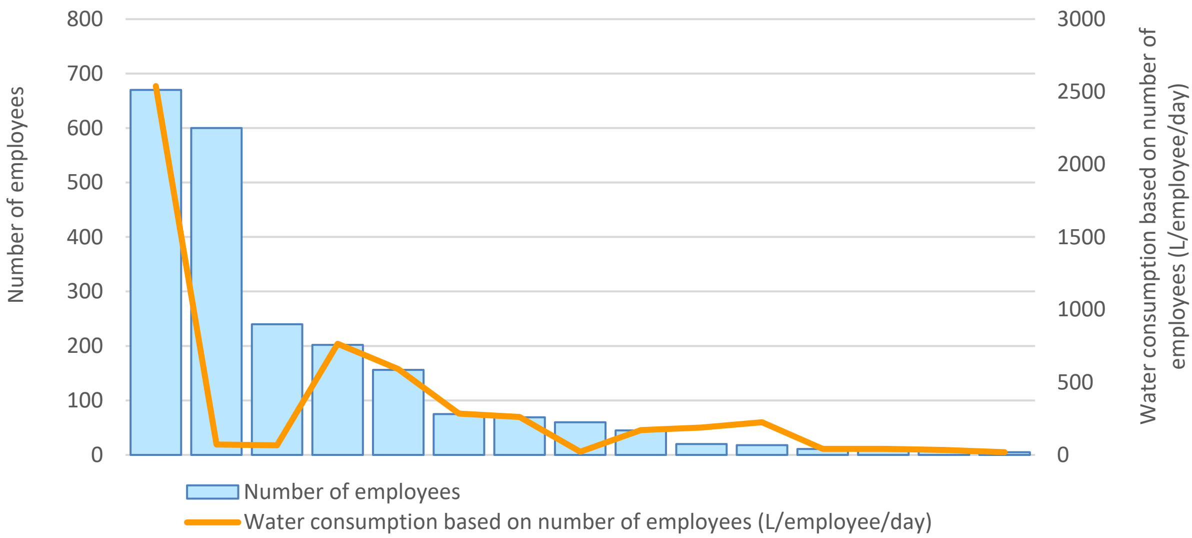


Figure 3 - 70 Number of employees vs daily per employee water consumption in the office

Based on the data collected and analyzed from several studies (Kieger et al. 2015), a plot of office water consumption and the number of employees in Figure 3 - 71 indicates a positive correlation. It indicates a maximum water consumption threshold beyond which the per employee water consumption increases with an increased employees number.

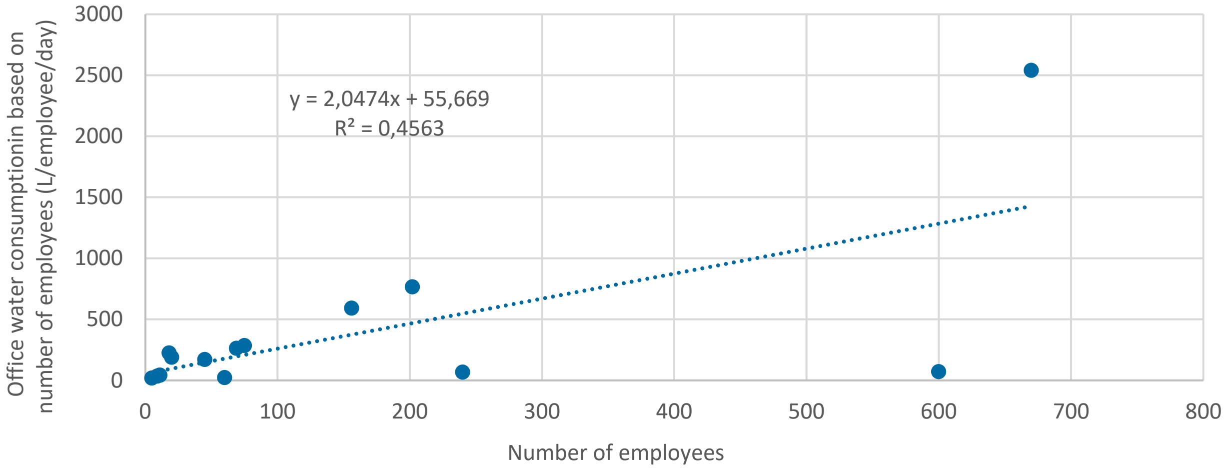


Figure 3 - 71 Correlation between office water consumption per employee and number of employees

3.3.4.3 Office water consumption findings

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of office water consumption is due to the following reasons:

- Bint et al. (2000) indicated that water consumption varies among buildings and geographic regions.
- Waggett & Arotsky (2006) mentioned that many office buildings consume more water than they need.
- BIS and Cranfield University (2009) indicated that the efficiency of restroom equipment and implementing recycling systems have an impact on office water consumption.
- Albrecht et al. (2009) stated that every facility defines its distinctive water balance to best target opportunities.
- Colorado WaterWise, (2010) pointed out that each office building has its combination of water consumption equipment.
- Edmunds & Associates (2011) mentioned that the types of water consumption data collected in offices differ among different countries.
- Cremona & Saliba (2012) stated that office water consumption varies according to employee numbers.
- Kieger et al. (2015) pointed out that various offices consume different amounts of water because of building functionality and design.
- The U.S. Energy Information Administration (2017) showed that working hours, the nature of the work, and building age make a difference in office building water consumption.

3.3.5 Wholesale and retail trade water consumption

There are limited studies on water consumption in wholesale and retail buildings (BIS and Cranfield University, 2009). For example, there is no estimation for wholesale and retail water consumption in the UK (Katie et al., 2013).

In 2007, Sydney Water developed the best wholesale and retail water consumption index. They estimated the average daily water consumption to be 2.48 L/m²/day (Sydney Water, 2007). The Beacon Countyline, a real estate developer in the USA, determined the average daily water consumption for retail as 60,640 L/day, equivalent to 2 L/m²/day (Countyline, 2008).

The best technique for assessing water consumption in wholesale and retail is through a bottom-up approach, and its best approximation is evaluated at 25 L/employee/day (BIS and Cranfield University, 2009).

Based on water account billings information, the St. Johns River Water Management District calculated the average water consumption index in wholesale and retail to be 2.49 L/m²/day (Jones edmunds & associates 2010).

Most of the water consumption in wholesale and retail is due to employee consumption (Katie et al., 2013). That occurs mainly in restrooms (Camp Dresser & McKee Inc., 2011).

A water plan and demand forecast have been developed in Oklahoma to define their consumption. Thus, water consumption in the wholesale and retail sectors was based on the number of employees. This can be defined as the total water consumption in each establishment on an average day divided by the number of employees, estimated in the range of 167-176 L/employee/day (Camp Dresser & McKee Inc., 2011).

In 2012, the U.S. Energy Information Administration (EIA) Office of Energy Consumption and Efficiency Statistics specified the water consumption index in the wholesale and retail sectors. This is based on a floor area of 0.37 L/m²/day and the number of employees, which was 113 L/employee/day (EIA, 2012).

From 2007 to 2010, there was no database to determine water consumption in wholesale and retail sectors in the UK. As a result, water consumption based on the number of employees was used as a benchmark since there was no significant difference in employment numbers. Water consumption was estimated in the wholesale and retail sectors as high as 32,054,795 L/day in 2007 and 32,328,767 L/day in 2010, while the lowest consumption was estimated at 21,917,808 L/day and the average estimate was 27,123,288 L/day (Katie et al. 2013).

3.3.5.1 Wholesale and retail trade water consumption micro-components analysis

Wholesale and retail buildings typically consume water in four major areas: restrooms, cooling and heating, irrigation, and kitchens (EBMUD, 2008).

To understand the nature of the water consumption breakdown, Watersmart Guidebook provides insights into the wholesale and retail water consumption micro-components percentage according to the following: 26% for restrooms, 21% for cooling and heating, 38% for irrigation, and 15% for kitchens (Jones Edmunds & Associates, 2010).

It is important to mention that the research found no more studies relating to water consumption breakdowns in the wholesale and retail trade. In fact, none of the studies found included reliable breakdown data.

3.3.5.2 Wholesale and retail trade water consumption distribution analysis

This analysis aims to determine the water consumption per floor area and employee in the wholesale and retail trade. Based on the data collected and analyzed from several studies (Water et al. 2006; Jones edmunds and associates 2010; Countyline 2008; Katie et al. 2013), the distribution of wholesale and retail trade water consumption is shown in Figure 3 - 72. From all the studies, the resulting average water consumed is 963,981 L/day. The remaining statistics are shown in the figure below.

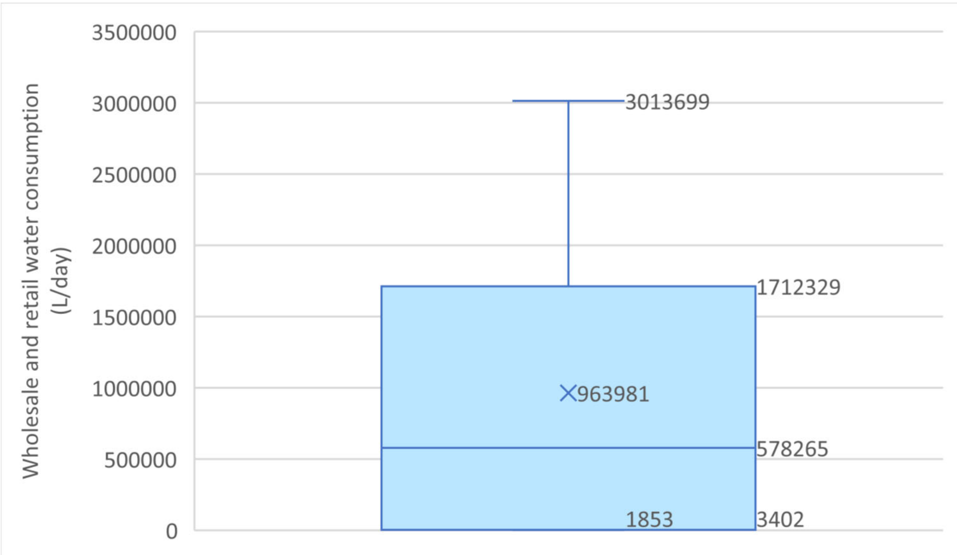


Figure 3 - 72 Distribution of daily water consumption in wholesale and retail

3.3.5.2.1 Daily wholesale and retail water consumption distribution based on floor area

The distribution of wholesale and retail trade water consumption per floor area, considering the wholesale and retail trade's total floor area, is shown in Figure 3 - 73, which presents the data collected and analyzed from several studies (Water et al. 2006; EIA, 2012 and Countyline 2008). From all the studies, the resulting average is 2.10 L/m²/day. The remaining statistics are shown in the figure below.

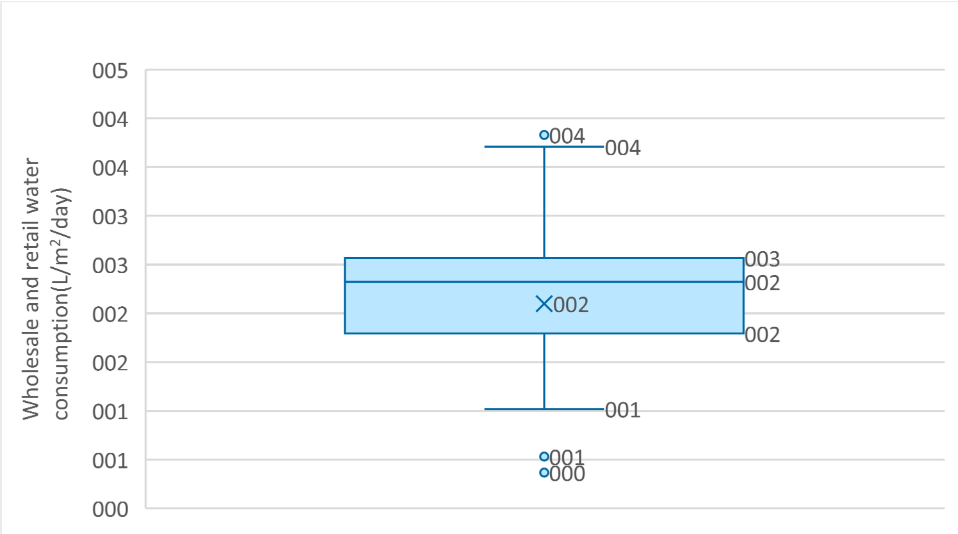


Figure 3 - 73 Distribution of daily per floor area water consumption in wholesale and retail trade

Based on the data collected and analyzed from several studies (Water et al. 2006), variation of wholesale and retail trade water consumption with respect to the wholesale and retail trade's total floor area is shown in Figure 3 - 74. From all the studies, the highest water consumption value per floor area was about 3.8 L/m²/day, and its floor area is about 471 m^2. In contrast, the lowest water consumption value per floor area was about 0.53 L/m²/day, and its floor area was about 5,042 m^2.

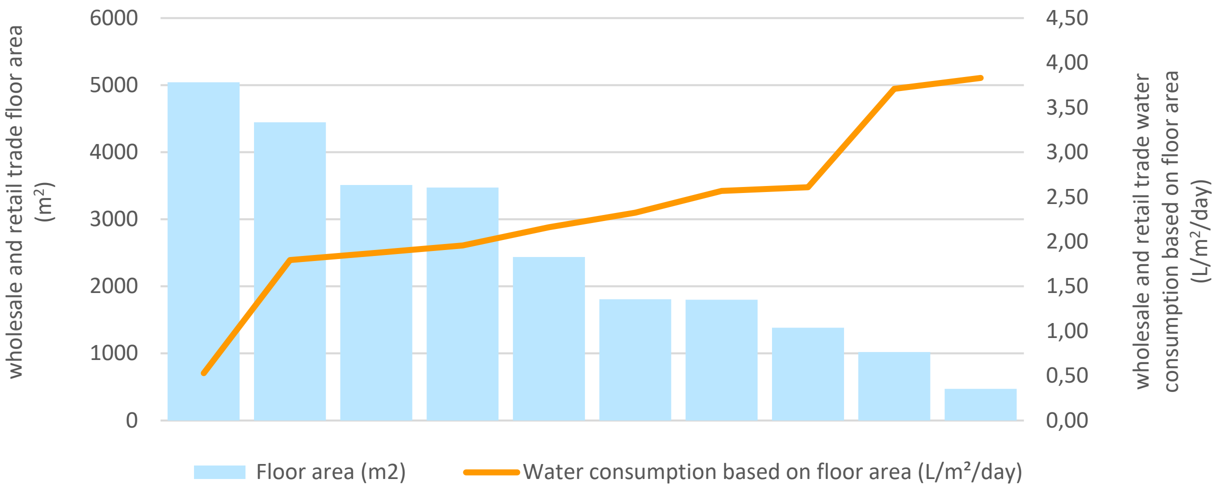


Figure 3 - 74 Wholesale and retail floor area vs daily water consumption in the wholesale and retail trade based on floor area

Based on the data collected and analyzed from several studies (Water et al. 2006), a plot of wholesale and retail trade water consumption and floor area presented in Figure 3 - 75 indicates a negative correlation. It indicates a minimum water consumption threshold beyond which the per unit area water consumption decreases with an increase in the area.

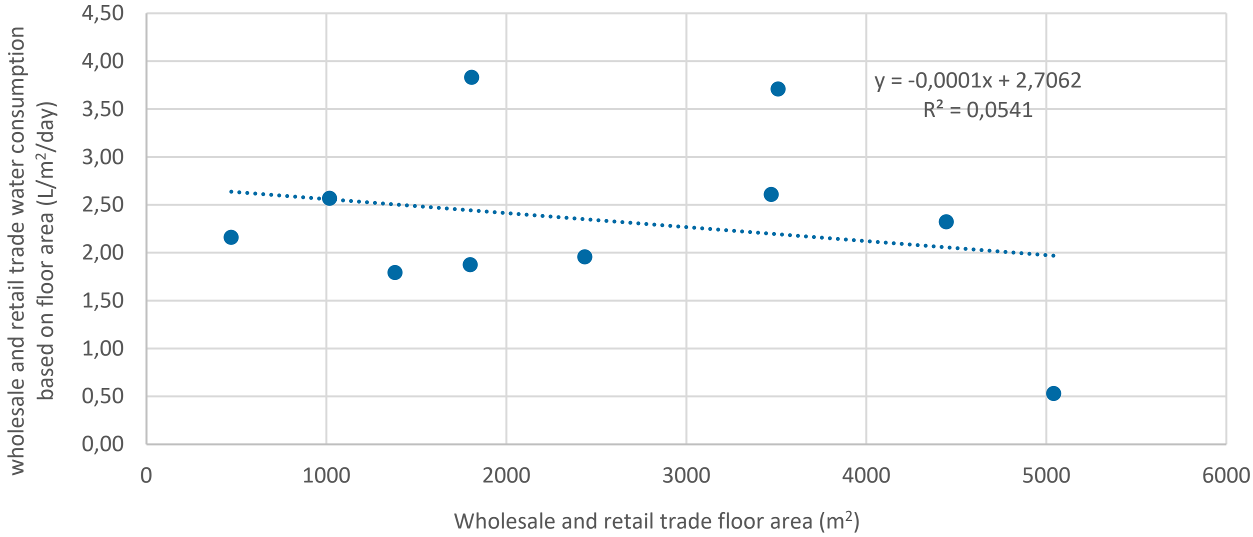


Figure 3 - 75 Correlation between wholesale and retail trade water consumption per floor area and wholesale and retail trade floor area

3.3.5.2.2 Daily water consumption in wholesale and retail trade-based number of employees

The distribution of wholesale and retail trade water consumption per employee, considering the wholesale and retail trade's employees number, is shown in Figure 3 - 76, which presents the data collected and analyzed from several studies (Camp Dresser & McKee Inc. 2011; BIS and Cranfield University 2009 and EIA, 2012). From all the studies, the resulting average is 120 L/employee/day. The remaining statistics are shown in the figure below.

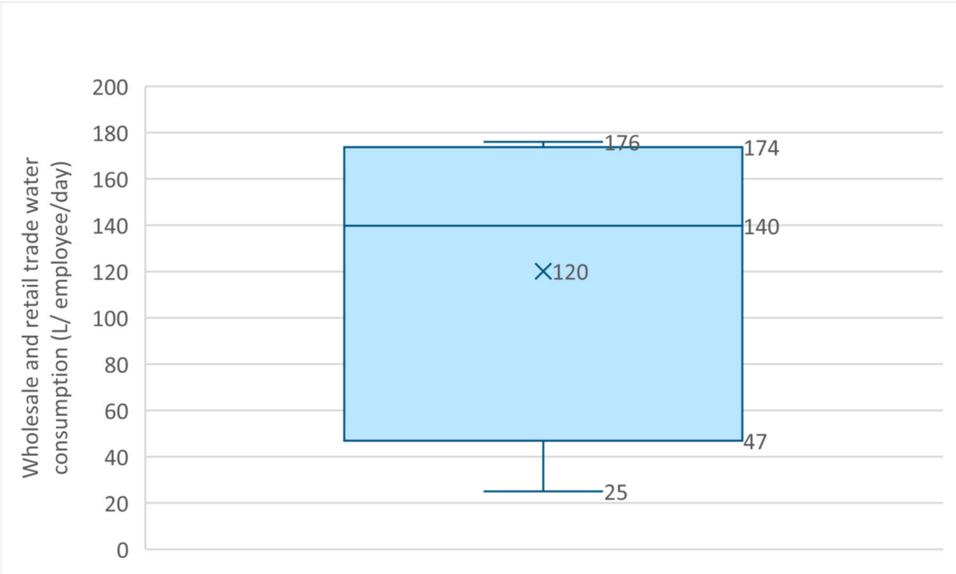


Figure 3 - 76 Distribution of daily per employee water consumption in wholesale and retail trade

The research did not find any previous work relating to the number of wholesale and retail trade employees with their total consumption. Therefore, when developing this thesis, it was impossible to derive how the per employee water consumption may change depending on the number of employees in wholesale and retail trade. In fact, none of the studies found included reliable data about the number of employees working in the wholesale and retail trade.

Unfortunately, wholesale and retail trade water consumption with their number of employees is not available when developing the thesis. Consequently, the correlation between wholesale and retail trade water consumption per employee and the number of employees cannot be visualized. So, this unitary water consumption needs to be further analyzed and investigated.

3.3.5.3 Wholesale and retail trade water consumption findings

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of wholesale and retail trade water consumption is due to the following reasons:

- A possible explanation for varying water consumption in the wholesale and retail trade sectors could be the presence and absence of cooling and heating, gardens, and kitchens. Another possibility is the building age, as the older buildings consume more water than the newer ones (Water et al. 2006).

3.3.6 Schools water consumption

In Brazil, a study was conducted to estimate water consumption in schools. Building characteristics, the number of students, and water meter readings were considered. It was observed that water consumption is located mainly in restrooms, followed by kitchens. The study's outcome was calculating school water consumption based on the number of students (total water consumption divided by the total number of students). The average consumption range was between 50 to 100 L/student/day (Ilha et al. 2005).

As mentioned in research conducted on more than 184 schools, the water consumption index in schools is within the range of 1.3 L/m²/day to 2.1 L/m²/day, which is equivalent to the range of 18 L/student/day to 28 L/student/day with a 95% confidence (Force, 2007b).

School water consumption depends on users' behaviour, usually evaluated as 19 L/student/day, but its realistic evaluation is 12-14 L/student/day (Hubert Loftus, 2008).

The United States Environmental Protection Agency (EPA) mentioned that the estimated school water consumption is 137918.1 L/day in Phoenix, Arizona and 330147 L/day in Denver, Colorado. (US EPA, 2009).

From 2005-2010, six hundred school water metering data studies were collected and analyzed to estimate water consumption. The results were that elementary schools consume within the range of 10 L/student/day to 30 L/student/day, with an average of 20 L/student/day. But its realistic estimation was 18 L/student/day (Farina et al., 2011).

It was expected that younger students need more services and consume more water. For example, in restrooms, washing, cleaning, and kitchens, compared to older students who consume less. Also, it was expected that school types (elementary, secondary, and high school) differ in water consumption. But it was observed that water consumption in all schools had similarities. Therefore, a general estimation of water consumption was proposed to be 30 L/student/day to 70 L/student/day for all schools, regardless of type (Farina et al., 2011).

In 2014, more than 2,799 schools were studied to determine their water consumption. The results assigned water consumption according to school type. Water consumption in primary schools was 26.8 L/student/day, while this consumption increased to 29.8 L/student/day in secondary schools. However, the best practice guide was proposed to be not more than 20 L/student/day (Environment-agency, 2014).

School water consumption was estimated to range from 13 L/student/day to 29 L/student/day. According to the following water consumption breakdown, restroom consumption was 9-22 L/student/day; wash basin consumption was 3-6 L/student/day and drinking fountain consumption was 1 L/student/day/day (Water Corporation 2015).

In a study conducted over seven schools, water metering data was gathered and analyzed. It was estimated that water consumption in elementary schools was 8.7 L/student/day, and in high schools, it was 30 L/student/day (Kieger et al. 2015).

In Florida, a study was conducted in the Tampa Bay region to determine school water consumption. The data on water consumption and the number of students for 151 schools were gathered from the Florida Department of Education (DOE). The study stated a positive relationship between water consumption in school and the number of students. Also, it was found that the average water consumption in both elementary and secondary school was 25 L/student/day, but in high school, it was 37 L/student/day (Kieger et al. 2015).

3.3.6.1 Schools water consumption micro-components analysis

School and educational facilities typically use water in these major areas: restrooms, irrigation, cooling and heating, and kitchens (New Mexico Office of the State Engineer, 1999).

The data analyzed by the New Mexico Office of the State Engineer stated in the water conservation guide for commercial, institutional, industrial users indicate the school water consumption micro-components to be 45% for restrooms, 25% for irrigation, 20% for cooling and heating, and 10% for the kitchen (Resort, 2006).

In 2008, the East Bay Municipal Utility District issued a Watersmart Guidebook, which contained characteristic of a water consumption breakdown in the schools as follows: 44% in the restrooms, 31% for the irrigation (gardens, etc.), 12% for the cooling and heating, and 13% for the kitchen (Jones Edmunds & Associates, 2010).

To understand the water consumption breakdown in schools, the United States Environmental Protection Agency (EPA) provides insight based on consumption data from different sources. This consumption breakdown includes 45% for restrooms, 28% for irrigation (gardens, etc.), 11% for cooling and heating, 7% for kitchens, 3% for other activities, which include unaccounted and unintentional use, 3% for laundries, and 1% for swimming pools.

Another study determined schools' water consumption breakdown percentage as 45% for restrooms, 25% for irrigation, 20% for cooling and heating and 10% for kitchens (Albrecht et al. 2009).

Albrecht et al. (2009) mentioned water consumption micro-components in schools to be 45% for restrooms, 25% for irrigation, 20% for cooling and heating, and 10% for the kitchen.

Based on the data collected and analyzed from these different studies (US EPA 2009; Resort 2006; Albrecht et al. 2009, and Jones Edmunds & Associates, (2010), the contribution of water consumption micro-components concerning total office water consumption is shown in Figure 3 - 77. The figure shows that the average contribution was 45% for restrooms, 28% for landscaping, 16% for cooling and heating, 10% for kitchens, 3% for laundries, and 1% for swimming pools.

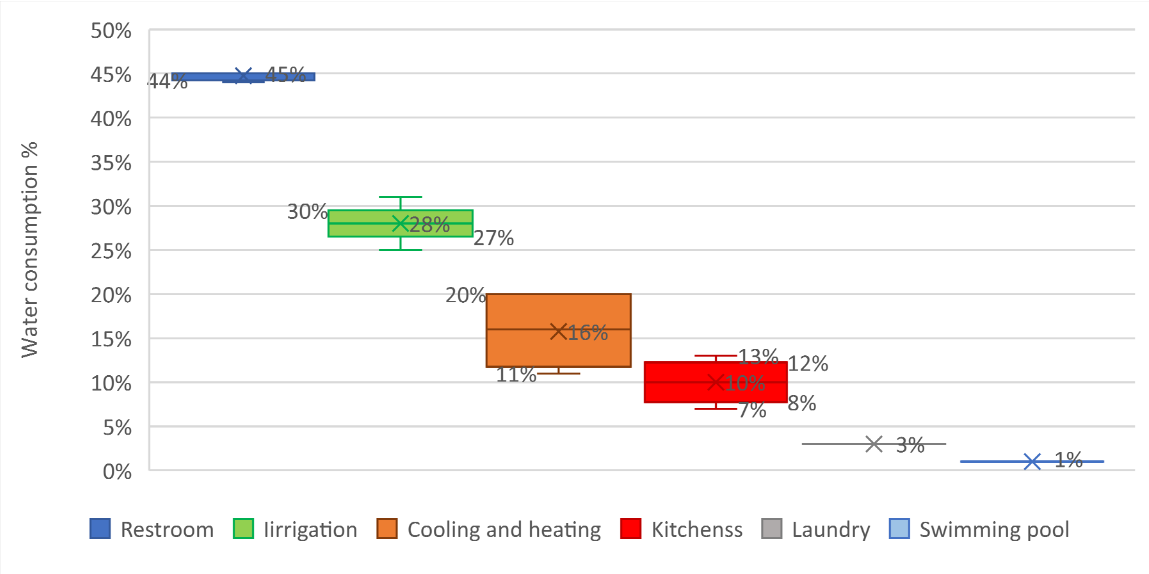


Figure 3 - 77 Analysis of water consumption micro-components in schools by use

3.3.6.2 Schools water consumption distribution analysis

This analysis aims to determine the water consumption per floor area and student in schools. Based on the data collected and analyzed from several studies (Farina et al., 2011; Kieger et al., 2015; US EPA, 2009), the distribution of school water consumption is shown in Figure 3 - 78. From all the studies, the resulting average water consumed is 238,000 L/day. The remaining statistics are shown in the figure below.

It is essential to mention that the research found no previous work relating to elementary, secondary, or high school water consumption. In fact, none of the studies found included reliable data about their total water consumption. So, this total distribution for schools in general without specifying the schools' categories.

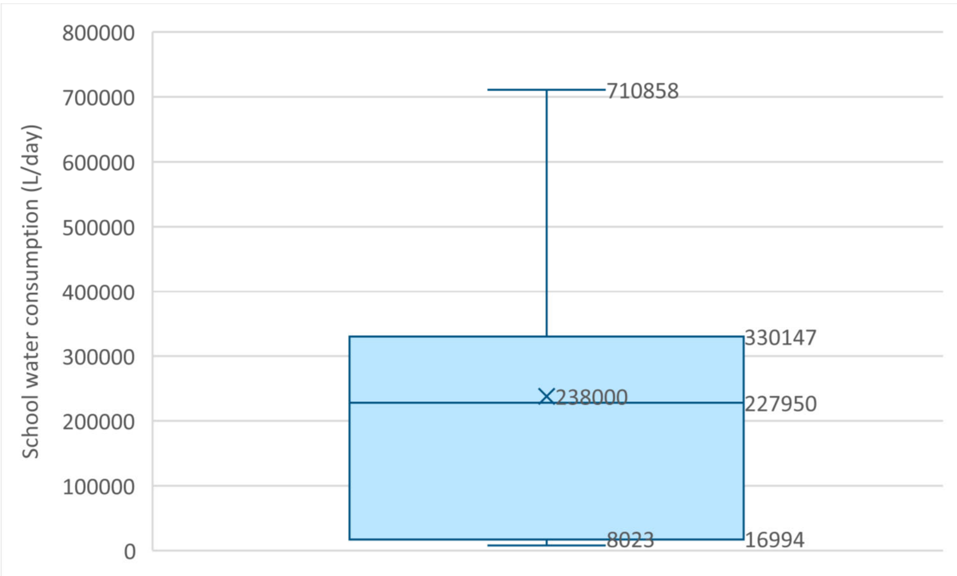


Figure 3 - 78 Distribution of daily water consumption in schools

3.3.6.2.1 Daily schools water consumption distribution based on floor area

The distribution of elementary, secondary, high school and schools in general water consumption per floor area, considering the school's total floor area, is shown in Figure 3 - 79, which presents the data collected and analyzed from several studies (Force, 2007and Georgia department of natural resources, 2004). From all the studies, the resulting average in the elementary, secondary, high schools, and schools as general is 1.9 L/m²/day, 2.1 L/m²/day, 2.1 L/m²/day, and 2.5 L/m²/day, respectively. The remaining statistics are shown in the figure below.

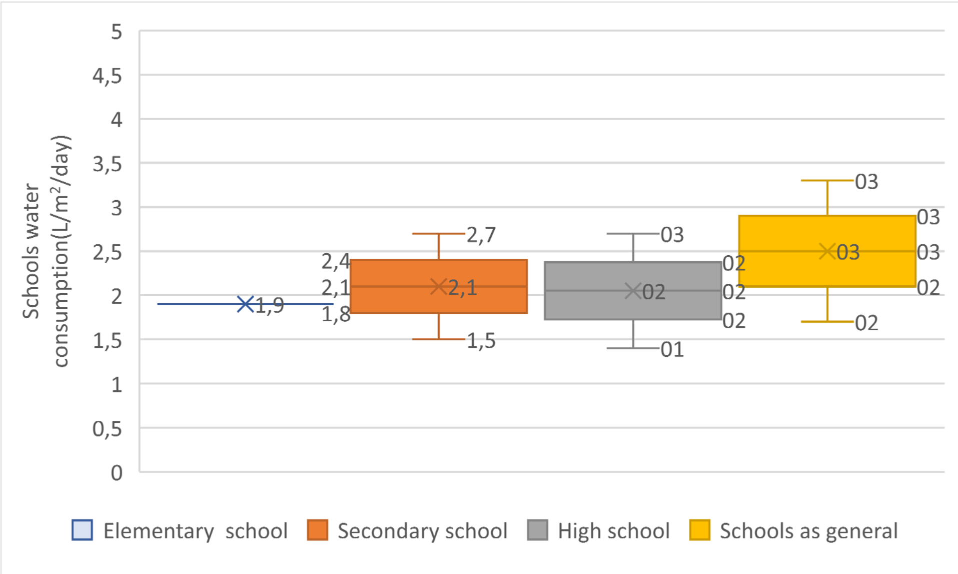


Figure 3 - 79 Distribution of daily water consumption in schools per floor area

The research conducted did not find any previous work relating to the floor area in a school with its total consumption. Therefore, when developing this thesis, it was impossible to derive how the per floor area water consumption may change depending on the floor area in a school. In fact, none of the studies found included reliable data about the floor area in the school.

Unfortunately, schools' water consumption per floor area is not available when developing the thesis. So, the correlation between school water consumption per floor area and floor area cannot be visualized. So, this unitary water consumption needs further analysis and investigation.

3.3.6.2.2 Daily water consumption analysis in schools based on the number of students

The distribution of water consumption per student for elementary, secondary, high schools and schools in general, is shown in Figure 3 - 80 (Ilha et al. 2005; Hubert Loftus 2008; Environment-agency 2014; Farina et al. 2011; Kieger et al. 2015; Agustina 2019; Force 2007; Water Corporation, 2015; Cheng & Hong, 2004). From all the studies, the resulting average consumption for elementary, secondary, high schools, and school in general are 26 L/student/day, 24 L/student/day, 32 L/student/day and 20 L/student/day, respectively.

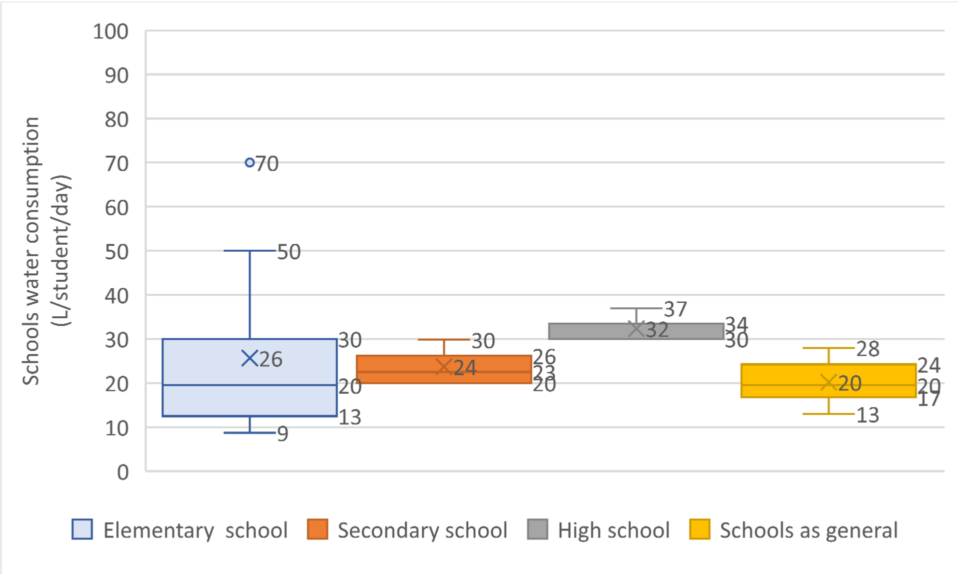


Figure 3 - 80 Distribution of daily per student water consumption in schools

The research conducted did not find any previous work relating to the number of students in a school with its total consumption. Therefore, when developing this thesis, it was impossible to derive how the per student water consumption may change depending on the number of students in a school. In fact, none of the studies found included reliable data about the number of students in the school.

Unfortunately, schools' water consumption with their number of students is not available when developing the thesis. So, the correlation between school water consumption per student and the number of students cannot be visualized. So, this unitary water consumption needs further analysis and investigation.

3.3.6.3 School water consumption findings

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of school water consumption is due to the following reasons:

- Schultz and Albuquerque (1999) mentioned that the plumbing fixture standards vary among schools, making differences in water consumption.
- Gleick et al. (2003) pointed out that working hours vary among schools, which could cause variations in their water consumption.
- Ilha et al. (2005) mentioned that the different activities carried out in schools could cause variations in their water consumption.
- Hubert Loftus (2008) indicated that water pressures and flow rates are set differently, leading to a variation in school water consumption.
- The US EPA (2009) stated that school water consumption could be affected by the number of restrooms or/and showers, canteen/kitchen equipment, working hours, and the number of events.
- Farina et al. (2011) pointed out that younger students consume more water daily than older students since they need more services. For example, the toilet is frequently used by younger students. Also, water consumption differs among the schools due to the variation in water use in their buildings.
- Agency (2016) and Edmunds & Associates (2011) indicated that older schools consume more water than newer schools.
- End-use water consumption in schools differs greatly due to the difference in the design and types of water equipment used among different types of schools.

3.3.7 University water consumption

Limited studies describe and analyze water consumption in universities. These limitations are due to the university campus's characteristics and the diverse properties mix, which differ considerably by size, location, climate, and equipment efficiency. Also, university water consumption is poorly described, and many use different methodologies or approaches to report their water consumption (Zhang, 2010).

From 1998 to 2002, the Universiti Teknologi Malaysia (UTM) studied water consumption on its campuses. The study was based on the monthly water billing data and campus population. It also analyzed the behaviour of water consumption on its campus by using a time series modelling approach (WIn, 1998). The total water consumption estimation was 6,027,397 L/day; in 2002, it was 8,356,164 L/day. The outcomes from the study determined the water consumption index in universities to be 260 L/capita/day (Katimon and Demun, 2004).

In 2007, Sydney Water estimated the average daily water consumption and the best water consumption index in a university to be 20 L/student/day (Sydney Water, 2007).

The University of California developed a study identifying the basic demand for water consumption in a university, where water consumption in various universities was studied and analyzed. They defined all users, including faculty, staff, and students, assuming 2,000 visitors per day, and their relation to water consumption., Additionally, the university floor area index water consumption was correlated. Because of water conservation practices, the estimation decreased from 243 L/capita/day in 1990, equivalent to 0.6 L/m^2/day, to 186 L/capita/day in 2009, equal to 0.40 L/m^2/day (Zhang, 2010).

More than fifty university building water bills were analyzed in another study over three years. The results were two water indexes for universities equivalent to each other. One was per capita-based. This was estimated as 47 L/capita/day in 2009, 44 L/capita/day in 2010, and 42 L/capita/day in 2011. The other one was based on the number of students. This was estimated as 56 L/student/day in 2009, 53 L/student/day in 2010, and 50 L/student/day in 2011. (Geographic et al., 2013).

The Water Research Foundation (WRF), a nonprofit corporation interested in municipal water, estimated that university water consumption was 0.44 L/m^2/day. When water consumption in a university is compared with (primary and secondary) school consumption, it will find the resulting consumption more than 200 times a school’s consumption. This is due to the landscaping area, swimming pools, and heating and cooling in universities (Kieger et al. 2015).

In 2015, the South face Energy Institute established benchmarking guides to help colleges and universities evaluate their water consumption and associate them with the ENERGY STAR index, which proposes average water consumption for more than 80 building types. It recommended that the water consumption index in the university should be 1.3 L/m^2/day. This index allows water consumption in university buildings to be easily recognized regardless of size (Southface Energy Institute, 2015).

The university's average water consumption in New York City was estimated at 13,110 L/day (Kieger et al. 2015). While in California, the average water consumption at Chapman University was estimated to be 767,658 L/day (Geographic et al., 2013).

In Sri Lanka, the University of Kelaniya developed a study to analyze water consumption on its campuses over three years. The study's outcomes were that the average daily water consumption in the university was estimated to be 618,377 L/day, equivalent to the water index of 63 L/capita/day (Lekamge et al. 2016).

The University of Technology, Sydney (UTS) is interested in improving water sustainability. So, it developed water conservation events over ten years on its campus. The result is that water consumption performance improved based on the number of students, from 26 L/student/day in 2002 to 15 L/student/day in 2011. The study also mentioned that the highest water consumption was 2 L/m²/day, and the lowest was 1.6 L/m²/day. (Roberts and Neale, 2016).

Because of the variety of activities conducted on university sites, evaluating one rate that can be accepted as demonstrative for all universities is unreasonable. Some university sites have different water supply sources, such as wells not recorded in the total water consumption. For this purpose, determining an allocation per person, reflecting only the consumption recorded from the network supply, does not effectively reflect the total amount of water consumption. Results of the analysis of water from the network supply in the Polytechnic University of Valencia, in the Campus of Vera, estimated the water consumption index to be 24.1 L/student/day (Agustina, 2019).

3.3.7.1 University water consumption micro-components analysis

Educational facilities, such as universities, typically use water in these major areas: restrooms, landscaping, cooling and heating, and kitchens (New Mexico Office of the State Engineer, 1999).

In 2008, the water consumption breakdown in the University of California campus was as follows: 27% for domestic—other buildings, 25% for domestic residence halls, 19% for lab buildings, 8% for irrigation, 11% for steam plants, and 10% for other consumption, which includes unaccounted and unintentional use (Zhang, 2010).

To understand the nature of the water consumption breakdown, “the Commercial Building Energy Consumption Survey” (CBECS) established the character of university water consumption based on the following: 45% for restrooms, 28% for irrigation, 11% for cooling and heating, 7% for dishwashing, and 5% for other consumption, which includes unaccounted and unintentional use; 3% for laundry, and 1% for swimming pools (Southface Energy Institute, 2015).

In 2016, the University of Technology Sydney (UTS) demonstrated a water consumption breakdown for their campus based on the consumption data of audits, surveys, and submetering data. The results were 35% for cooling and heating, 20% for restrooms, 20% for kitchens, 13% for labs; 5% for other consumption, which includes unaccounted and unintentional use; 5% for irrigation, and 2% for the mechanical plant (Roberts and Neale 2016).

The typical water consumption micro-components in educational facilities are restrooms, landscaping, cooling and heating, and kitchens (New Mexico Office of the State Engineer, 1999). Since the water consumption micro-components in universities differ from one study to another, the common micro-components between the above studies and typical water consumption micro-components in educational facilities can be assumed to be the university water consumption micro-components.

Based on the data collected and analyzed from these different studies (Roberts and Neale 2016 and Southface Energy Institute 2015), the university's water consumption micro-components are shown in Figure 3 - 81, which presents the data collected and analyzed from several studies (Roberts and Neale 2016 and Southface Energy Institute 2015). As shown in the figure, the average contribution was 33% for restrooms, 17% for irrigation, 23% for cooling and heating, 20% for kitchen, 3% for laundry, 1% for swimming pools and 5% for other, including unaccounted and unintentional use.

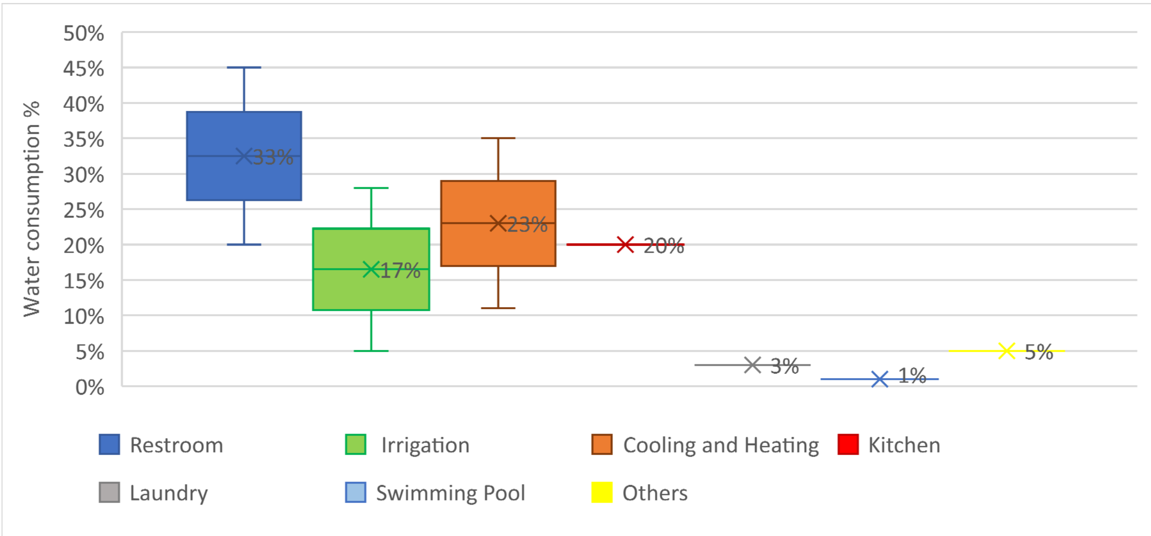


Figure 3 - 81 Analysis of water consumption micro-components in universities by use

3.3.7.2 University water consumption distribution analysis

This analysis aims to determine the amount of water consumption per capita, floor area, and student in the university. Based on the data collected and analyzed from several studies (Kieger et al. 2015; Lekamge et al. 2016; Southface Energy Institute 2015; Geographic et al. 2013 and Katimon and Demun 2004), the distribution of university water consumption is shown in Figure 3 - 82. From all the studies, the resulting average water consumed is 2,647,760 L/day. The remaining statistics are shown in the figure below.

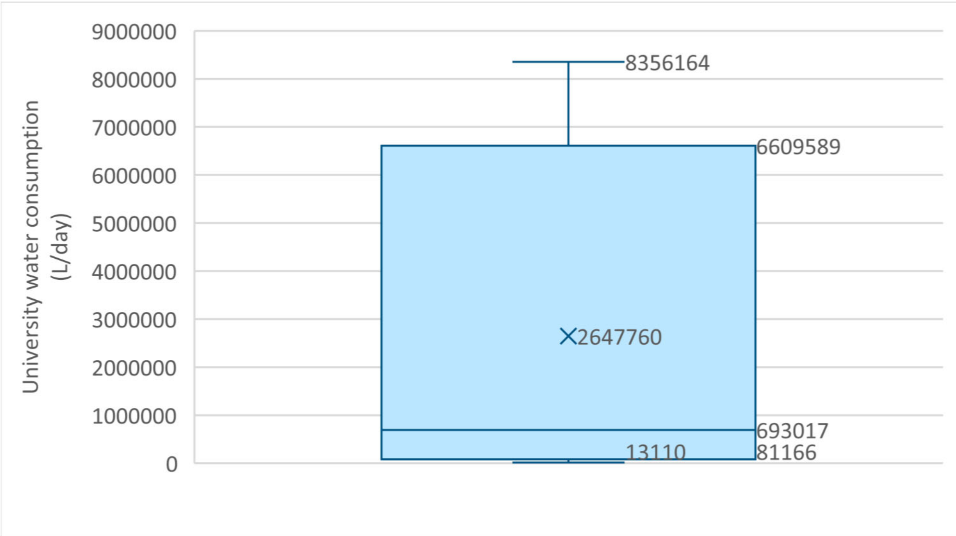


Figure 3 - 82 Distribution of daily water consumption in the university

3.3.7.2.1 Daily water consumption per capita in university

The distribution of university water consumption per capita, considering the university's total population, is shown in Figure 3 - 83, which presents the data collected and analyzed from several studies (Zhang 2010; Kieger et al. 2015; Lekamge et al. 2016; Southface Energy Institute 2015; Geographic et al. 2013 and Katimon and Demun 2004). From all the studies, the resulting average is 126 L/capita/day. The remaining statistics are shown in the figure below.

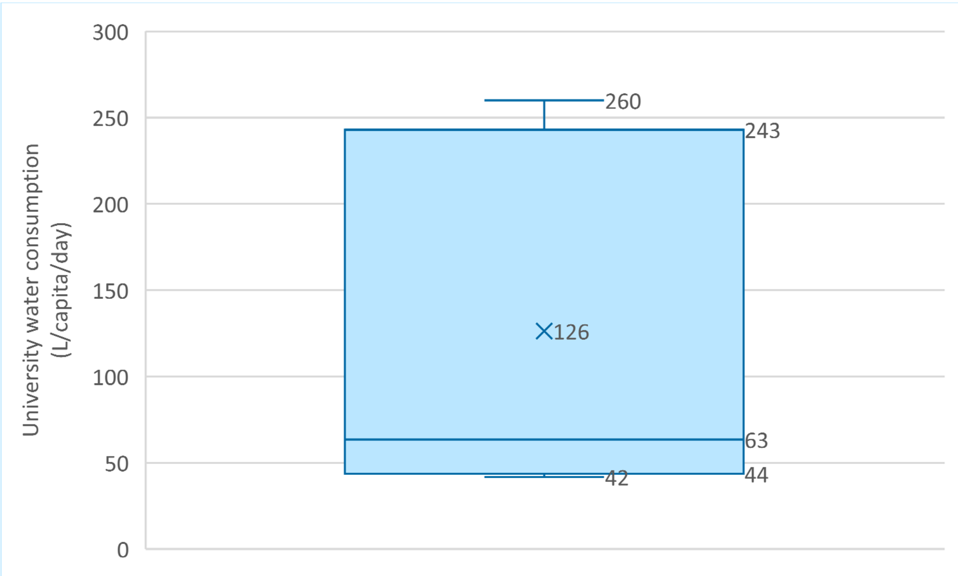


Figure 3 - 83 Distribution of daily per capita water consumption in university

The research conducted did not find any previous work relating to the per capita in a university with its total consumption. Therefore, when developing this thesis, it was impossible to derive how the per capita water consumption may change depending on the per capita in a university. In fact, none of the studies found included reliable data about the per capita in the university.

Unfortunately, universities' water consumption with their per capita is not available when developing the thesis. Consequently, the correlation between university water consumption per capita and university per capita cannot be visualized. So, this unitary water consumption needs further analysis and investigation.

3.3.7.2.2 Daily university water consumption distribution per floor area

The distribution of university water consumption per floor area, considering the university's total floor area, is shown in Figure 3 - 84, which presents the data collected and analyzed from several studies (Zhang 2010; Kieger et al. 2015; Georgia department of natural resources 2004; Southface Energy Institute 2015 and Roberts and Neale 2016). From all the studies, the resulting average is 1.07 L/m²/day. The remaining statistics are shown in the figure below.

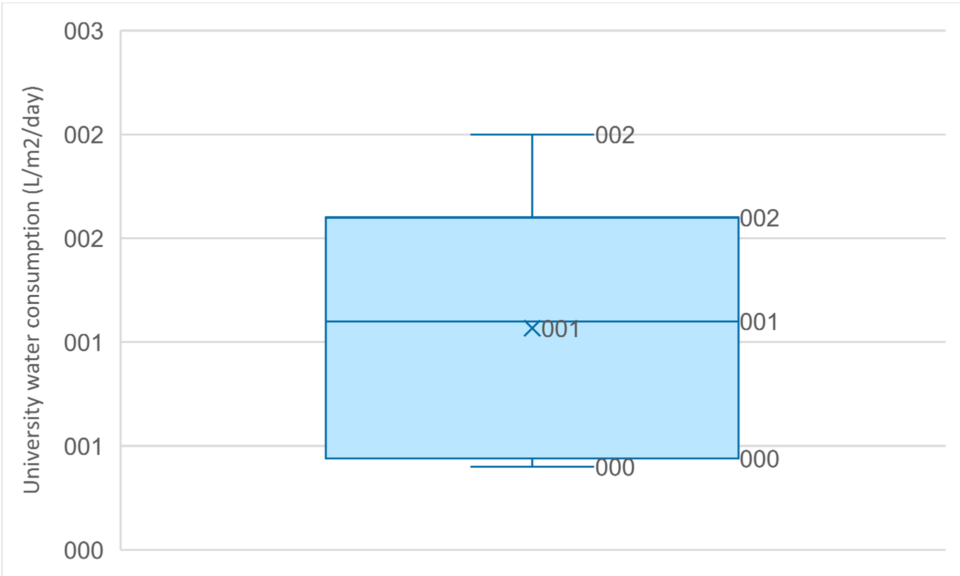


Figure 3 - 84 Distribution of daily per floor area water consumption in the university

The research conducted did not find any previous work relating to the floor area in a university with its total consumption. Therefore, when developing this thesis, it was impossible to derive how the per floor area water consumption may change depending on the floor area in a university. In fact, none of the studies found included reliable data about the floor area in the university.

Unfortunately, universities' water consumption associated with the floor area is not available when developing the thesis. Consequently, the correlation between university water consumption based on floor area and university floor area cannot be visualized. So, this unitary water consumption needs further analysis and investigation.

3.3.7.2.3 Daily university water consumption distribution based on the number of students

The distribution of university water consumption per student, considering the total number of students, is shown in Figure 3 - 85, which presents the data collected and analyzed from several studies (Agustina 2019; Geographic et al. 2013; Roberts and Neale 2016). From all the studies, the resulting average is 37 L/student/day. The remaining statistics are shown in the figure below.

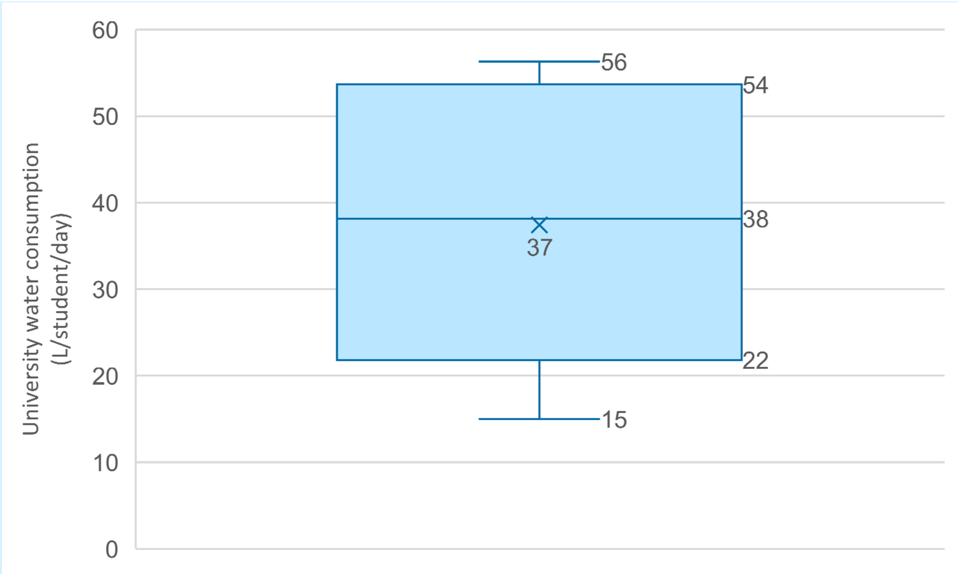


Figure 3 - 85 Distribution of daily per student water consumption in university

The research conducted did not find any previous work relating to the number of students in a university with its total consumption. Therefore, when developing this thesis, it was impossible to derive how the per student water consumption may change depending on the number of students in a university. In fact, none of the studies found included reliable data about the number of students in the university.

Unfortunately, universities' water consumption with their number of students is not available when developing the thesis. Consequently, the correlation between university water consumption per student and the number of students cannot be visualized. So, this unitary water consumption needs further analysis and investigation.

3.3.7.3 University water consumption findings

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of university water consumption is due to the following reasons:

- DPPEA (2009) pointed out that each university decides its water balance to the best target index.
- Zhang (2010) indicated that university water consumption is not reported and varies significantly by location and the efficiency of water usage in their buildings.
- Kieger et al. (2015) stated that water consumption varies due to the diversity of activities performed on university campuses.
- Lekamge et al. (2016) mentioned that human habits could affect water consumption, for example, the number of people taking lunch and/or dinner on campus.
- Jackie D. Urrutia et al. (2017) pointed out that days off differ among universities, making their water consumption vary.

3.3.8 Hospital water consumption

Hospitals are among the highest water users (K. Taddonio, 2015). It is estimated that hospitals and their medical facilities usually consume around 15% of the municipal water supply (Sood, 2016). For example, the Danish hospitals' estimated annual water consumption was 1 million m^3 (Jakobsen and Nielsen, 2016). So, the municipal water supply is stressed by water consumption in hospitals, especially in dry areas, because of the obligation to supply water to hospitals without shortage (S. Bungau et al. 2015).

In 1993, it was estimated that the water consumption index in a hospital was highly dependent on the number of beds. So, the following water consumption indexes were developed accordingly. In hospitals with more than 100 beds, their water consumption was estimated to be from 513 L/bed/day to 710 L/bed/day. When the bed capacity increased to more than 25,000 beds, consumption was estimated to be 331 L/bed/day to 411 L/bed/day. Finally, when capacity was less than 2,500 beds, it was estimated to be in the range of L/bed/day 218 to 297 L/bed/day (Audit Commission, 1993).

In the UK, the average water consumption in hospitals was estimated to be between 530 L/bed/day to 1,138 L/bed/day (Audit Commission for Local Authorities in England and Wales, 1993).

The water consumption index in the hospital was proposed by the Handbook of Water Use and Conservation to be 1,137 L/bed/day (Wastewatergardens 2000 and Vickers 2001).

In Germany, hospitals' average water consumption index ranged from 456 L/bed/day (Reller, A. 2003) to 679 L/bed/day (Dettenkofer et al. 2000).

In 2003, Water UK revealed the results of a study performed on hospital water meters which were analyzed. The results expressed that the water consumption index in hospitals was based on the floor area to be 4.5 L/m²/day (Water UK 2003).

In 2007, Sydney Water evaluated the best benchmark water consumption in hospitals based on the number of beds of 271 L/bed/day (Sydney Water, 2007).

In the USA, hospitals' average daily water consumption was estimated to be 300 L/bed/day to 1,514 L/bed/day (Virginia Department of Transportation, 2008; Washington State Department of Health, 2009).

Different studies and research (Verlicchi et al. 2010; Mesdaghinia AR et al. 2009 and Guidelines of Region Emilia-Romagna 2009) showed that the water consumption index in hospitals was based on the number of beds. Where it was estimated to be 200 L/bed/day to 1,200 L/bed/day, this range represented the lowest water consumption index in hospitals in unindustrialized countries and the highest in industrial countries.

In Italy, over 36 hospitals in the Lombardy Region were engaged in ad hoc questionnaire studies, which concerned developing water consumption correlations. After analysis, it showed a strong correlation between water consumption and the number of beds ($p < 0.005$), with an average consumption of 481,000 L/day (Paolo Stanzione and Tropepi, 2011). Similarly, D'Alessandro et al. (2016) mentioned a clear correlation between hospital water consumption and the number of beds.

Contrary to the above studies, Alfonsi et al. 2014 and Verlicchi et al. 2010 reported no correlation between hospital water consumption based on the number of beds.

In the study "Commercial and Institutional End Uses of Water" (2000), the water billing information of five water agencies in Southern California and Arizona over one year was collected and analyzed. The study outlined the hospital's water consumption index as 182 L/capita/day (US EPA, 2009). While in another study, estimated water consumption in the hospital was 152 L/capita/day to 1,327 L/capita/day. This variation is due to different factors, such as location, services provided, size, age, type of buildings, and water equipment (Hospital Energy Alliance, 2011).

In Canada, one of the highest hospital water consumption estimations was estimated to be from 900 L/bed/day to 1,800 L/bed/day (ENVC 2011).

In the USA, a survey was implemented on water consumption in hospitals. Water metering data were collected from 88 water producers' facilities. For example, the water consumption index in Illinois was 6.7 $L/m^2/day$; in Wisconsin, it was 4 $L/m^2/day$; in Michigan, it was 5 $L/m^2/day$; and in Indiana, it was 4.5 $L/m^2/day$. The result of the survey was to obtain an overall average water consumption index, which, based on the hospital floor area, was 5.5 $L/m^2/day$ (Hospital Energy Alliance, 2011).

By contrast, they developed a comprehensive water plan and demand forecast in Oklahoma. It was stated that the water consumption index in hospitals—based on the number of employees—was estimated to be 321 L/employee/day (Camp Dresser and McKee Inc. 2011).

The water consumption portfolio of more than 50,000 buildings was monitored by the U.S. Environmental Protection Agency (EPA). Accordingly, the water consumption index in the hospitals was estimated to be 1,194 L/bed/day (EPA, 2012). While another study reported that water consumption in the hospital—based on the number of beds—is in the domain of 569 L/bed/day to 948L/bed/day (the Revisor of Statutes, 2012). This was close to another study, which estimated consumption at 948 L/bed/day (Parks, 2012) and a third one with 910 L/bed/day (Siplon, 2013).

Different factors affect the total amount of water consumption in hospitals which are locations, water resources, water networks, type and age of the buildings, size of the hospital, number of services provided, bed number and polyclinic capacities, number of patients and staff, and policies, (Topbas et al. 2016; Verlicchi P et al. 2010 and World Health Organization 2010). So, standardizing a water consumption approach estimation in hospitals is necessary (Department of Health, 2013).

In Cyprus, water consumption in hospitals was estimated to be 150 L/patient/day to 1,500 L/patient/day (O. Ozkan et al. 2014).

In Spain, Gonzalez et al. (2015) stated that the water consumption index in hospitals was 534 L/bed/day.

In 2016, a survey of water management was conducted in Turkey hospitals. The knowledge and opinions of 23 private and public hospital managers were collected and analyzed regarding water management. Water bills were studied and evaluated, as well, to estimate their water consumption. The result showed that the best average daily consumption in the hospital was estimated to be 165,400 L/day (Topbas et al., 2016). Another study estimated that water consumption was 113,700 L/day (Services, 2013). Danish hospitals' average water consumption was 400,000 L/day to 600,000 L/day (Jakobsen and Nielsen, 2016). The best explanation for these consumption variations could be that hospitals connected to the network and with a 24/7 water supply consume more water than hospitals with intermittent supply (Sood, 2016).

Water consumption in hospitals might differ according to the type of service provided, but all of them tend to consume about 500 to 700 L/bed/day. This is because they have a common requirement for water for ablution, drinking, washing, cleaning, sterilization, laundry, and catering (Sood, 2016).

In Denmark, the Ministry of Environment and Food developed a study in the hospital to obtain an outline of water resources, end-use, and water efficiency. The study performed water audits to identify the distribution of water consumption and specified the main source of consumption. The results of the study proposed two water consumption indexes. One was based on the hospital floor area, which was between 0.47 $L/m^2/day$ and 2.19 $L/m^2/day$. The other index was based on the number of beds, estimated to be between 570 L/bed/day and 710 L/bed/day. The Danish estimation was higher than the German, which was between 293 L/bed/day to 389 L/bed/day and the English which was between 330 L/bed/day to 410 L/bed/day (Jakobsen and Nielsen, 2016) and lower than Cuban, which was estimated at 805 L/bed/day (García-Sanz-calcedo et al., 2017).

In India, it was estimated that hospitals with more than 100 beds consumed between 450 L/capita/day and 135 L/capita/day in nurses and staff quarters (Balwani and Nagarnaik, 2017).

Based on 13 Spanish hospitals, average water consumption was calculated. The study used the hospital floor area and the number of beds as a water consumption index. It was estimated at 975 L/bed/day and 6.1 $L/m^2/day$ (García-Sanz-calcedo et al., 2017).

The Mexican Institute of Water Technology determined a daily water consumption in hospitals at 800 L/bed/day (García-Sanz-calcedo et al., 2017). This determination was higher than what the Pan American Health Organization studies determined, which was 450 L/bed/day (García-Sanz-calcedo et al., 2017).

3.3.8.1 Hospital water consumption micro-components analysis

Hospitals typically consume water in six major areas: restrooms, cooling and heating, medical equipment and processes, irrigation, kitchens, and laundries.

In Australia, the Victorian Government Department of Health (2009) displayed that a hospital water consumption breakdown with the largest water consumption was related to different activities conducted in washing, food preparation, cooling and heating, cleaning, drinking, and sanitizing.

The data analyzed by the New Mexico office of the state engineer stated that hospital water consumption micro-components were 40% for restrooms, 5% for irrigation, 10% for cooling and heating, 10% for laundry, 8% for kitchens and 27% for other consumption, which includes unaccounted and unintentional use (Resort, 2006).

In 2002, the Metropolitan Water District of Southern California (MWD) conducted water consumption audits in hospitals, which illustrate the characteristic of water consumption micro-component as follows: 25% for restrooms, 27% for cooling and heating, 22% for medical equipment, 8% for kitchens, 2% for laundries, and 16% for irrigation.

To understand the nature of water consumption breakdown, the United States Environmental Protection Agency (EPA) provided insights into hospital water consumption based on the average of several consumption accounts from different sources. The hospital water consumption breakdown was as follows: 35% consumed by restrooms, 20% consumed by cooling and heating, 15% consumed by medical equipment, 7% consumed by irrigation, 7% consumed by kitchens, 9% consumed by laundries, and 7% consumed by other sources, which includes unaccounted and unintentional use (US EPA, 2009).

In 2008, the East Bay municipal utility district issued a Watersmart Guidebook, which contained characteristics of water consumption in the office schools as follows: 31% in restrooms, 23% for cooling and heating, 10% for irrigation (gardens, etc.), 7% for kitchens, 6% for laundries, 22% for other consumption, including unaccounted and unintentional use (Jones Edmunds & Associates, 2010).

Albrecht et al. (2009) mentioned water consumption micro-components in hospitals at 40% for restrooms, 16% for medical equipment, 13% for cooling and heating, 8% for kitchens, 5% for irrigation, and 8% for others, including unaccounted and unintentional use.

According to Massachusetts Water Resources Authority, hospital water consumption micro-components were as follows: 40% for restrooms, 23% for cooling and heating, 14% for medical equipment, 9% for kitchens, 5% for laundries, and 9% for other, including unaccounted and unintentional use (Hospital Energy Alliance, 2011).

Based on the data collected and analyzed from these different studies (Albrecht et al. 2009; US EPA 2009; Hospital Energy Alliance 2011; Jones Edmunds & Associates, 2010; MWD 2002 and Resort 2006), the contribution of water consumption micro-components concerning total hospital water consumption is shown in Figure 3 - 86. The figure shows that the average contribution was 35% for restrooms, 9% for irrigation, 19% for cooling and heating, 8% for kitchens, 15% for other sources, including unaccounted and unintentional use, 7% for laundries and 17% for medical processes.

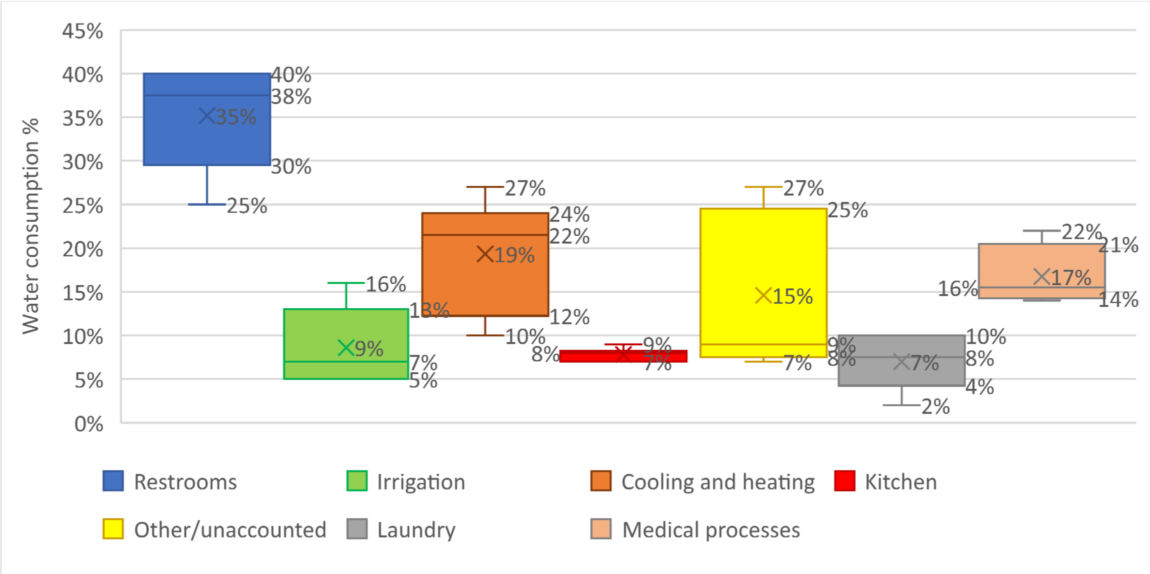


Figure 3 - 86 Analysis of water consumption micro-components in hospitals by use

3.3.8.2 Hospital water consumption distribution analysis

This analysis aims to determine the amount of water consumption per capita, floor area, and bed in the hospital. Based on the data collected and analyzed from several studies (Paolo Stanzione and Tropepi 2011; Jakobsen and Nielsen 2016; Topbas et al. 2016 and services 2013), the distribution of total hospital water consumption is shown in Figure 3 - 87. From all the studies, the resulting average water consumed is 298,350 L/day. The remaining statistics are shown in the figure below.

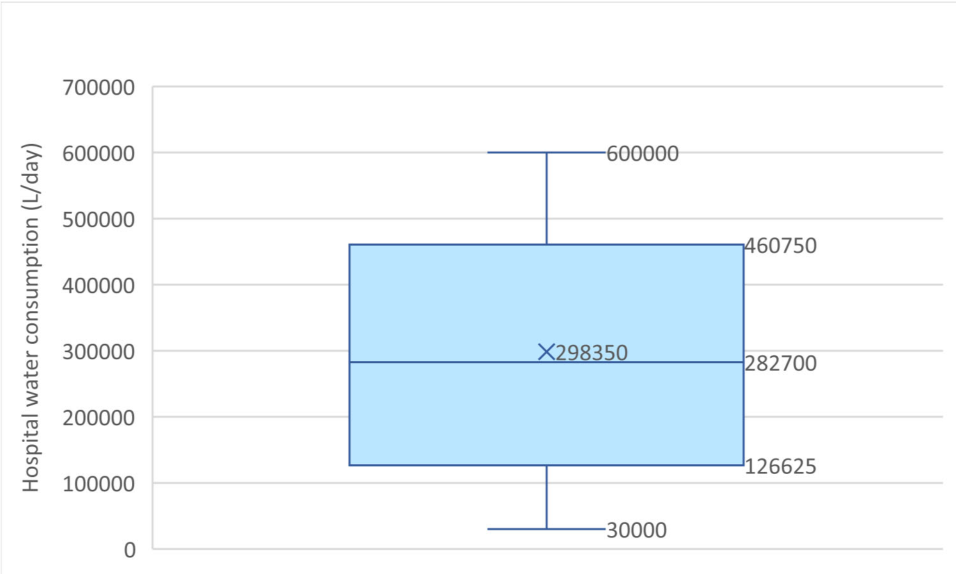


Figure 3 - 87 Distribution of daily water consumption in hospital

3.3.8.2.1 Daily hospital water consumption distribution based on per capita

The distribution of hospital water consumption per capita, considering the hospital's total population, is shown in Figure 3 - 88, which presents the data collected and analyzed from several studies (Parks 2012; Parks 2012; Hospital Energy Alliance 2011 and Balwani and Nagarnaik 2017). From all the studies, the resulting average is 528 L/capita/day. The remaining statistics are shown in the figure below.

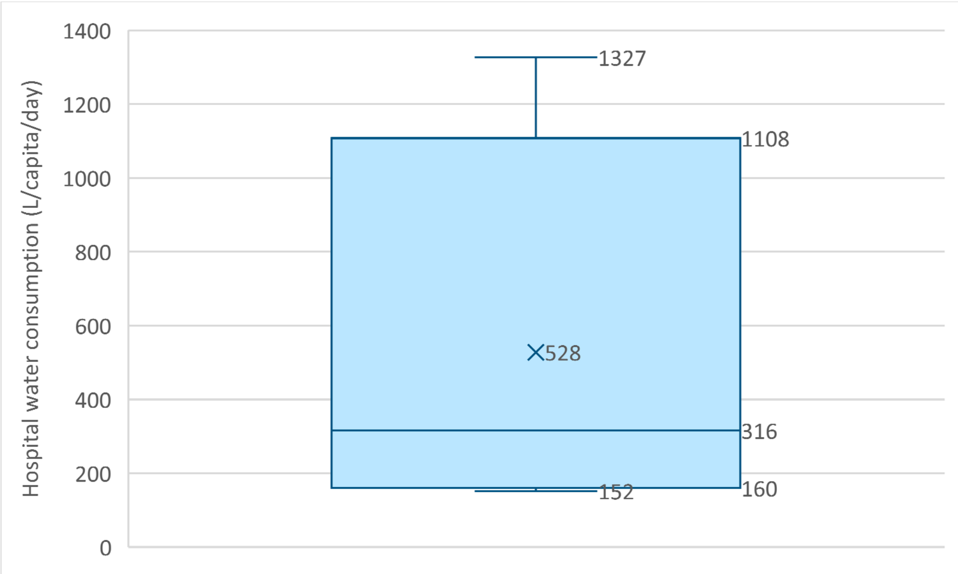


Figure 3 - 88 Distribution of daily per capita water consumption in a hospital

The research conducted did not find any previous work relating to the per capita in a hospital with its total consumption. Therefore, when developing this thesis, it was impossible to derive how the per capita water consumption may change depending on the per capita in a hospital. In fact, none of the studies found included reliable data about the per capita in the hospital.

Unfortunately, hospitals' water consumption with their per capita is not available when developing the thesis. Consequently, the correlation between hospital water consumption per capita and hospital per capita cannot be visualized. So, this unitary water consumption needs further analysis and investigation.

3.3.8.2.2 Daily hospital water consumption distribution based on floor area

The distribution of hospital water consumption per floor area, considering the hospital's total floor area, is shown in Figure 3 - 89, which presents the data collected and analyzed from several studies (Survey 2015; Water UK 2003 and García-Sanz-calcedo et al. 2017). From all the studies, the resulting average is 4.4 L/m²/day. The remaining statistics are shown in the figure below.

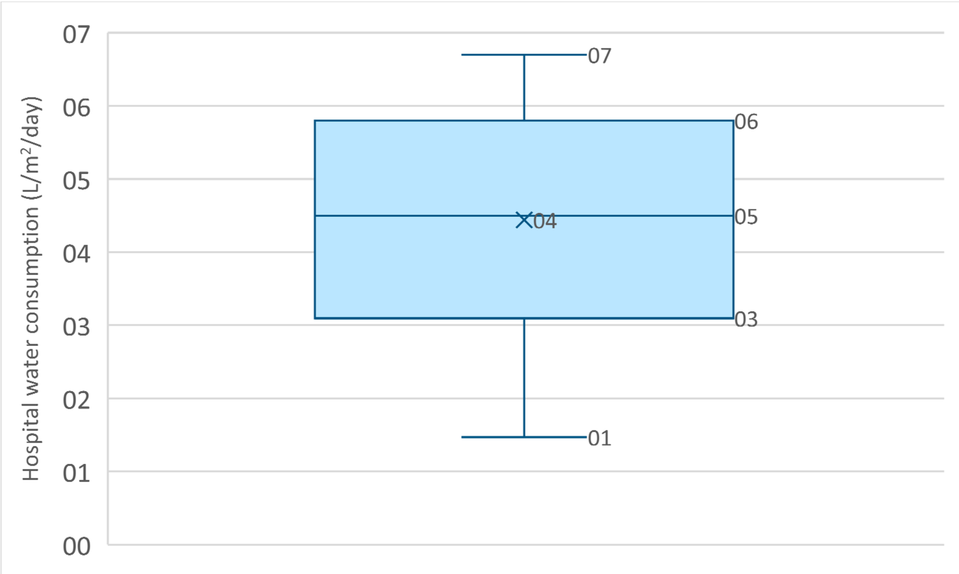


Figure 3 - 89 Distribution of daily per floor area water consumption in a hospital

The research conducted did not find any previous work relating to the floor area in a hospital with its total water consumption. Therefore, when developing this thesis, it was impossible to derive how the per floor area water consumption may change depending on the floor area in a hospital. In fact, none of the studies found included reliable data about the floor area in the hospital.

Unfortunately, the hospitals' water consumption associated with the floor area is not available when developing the thesis. Consequently, the correlation between water consumption in the hospital based on the floor area and floor area cannot be visualized. So, this unitary water consumption needs further analysis and investigation.

3.3.8.2.3 Daily water consumption analysis in hospitals based on the number of beds

The distribution of hospital water consumption per bed, considering the hospital's total beds number, is shown in Figure 3 - 90. It presents the data collected and analyzed from several studies (Sood, 2016; Parks, 2012; Wastewater gardens, 2000; The Revisor of Statutes, 2012; Vickers, 2001; Sydney Water, 2007; EPA, 2012; Hospital Energy Alliance, 2011; Audit Commission, 1993; Wastewatergardens 2000; Verlicchi et al. 2010; Mesdaghinia AR et al. 2009; Guidelines of Region Emilia-Romagna et al. 2009; García-Sanz-calcedo et al. 2017; institute of Environmental Medicine and Hospital Hygiene. 2002; Virginia Department of Transportation, 2008; Washington State Department of Health, 2009; Audit Commission for Local Authorities in England and Wales, 1993; Reller, A. 2003; Dettenkofer et al. 2000; González, et al. 2016; ENVC 2011; García-Sanz-calcedo et al. 2017; Jakobsen and Nielsen 2016; Siplon 2013). The resulting average distribution is 569 L/bed/day from all the studies. The remaining statistics are shown in the figure below.

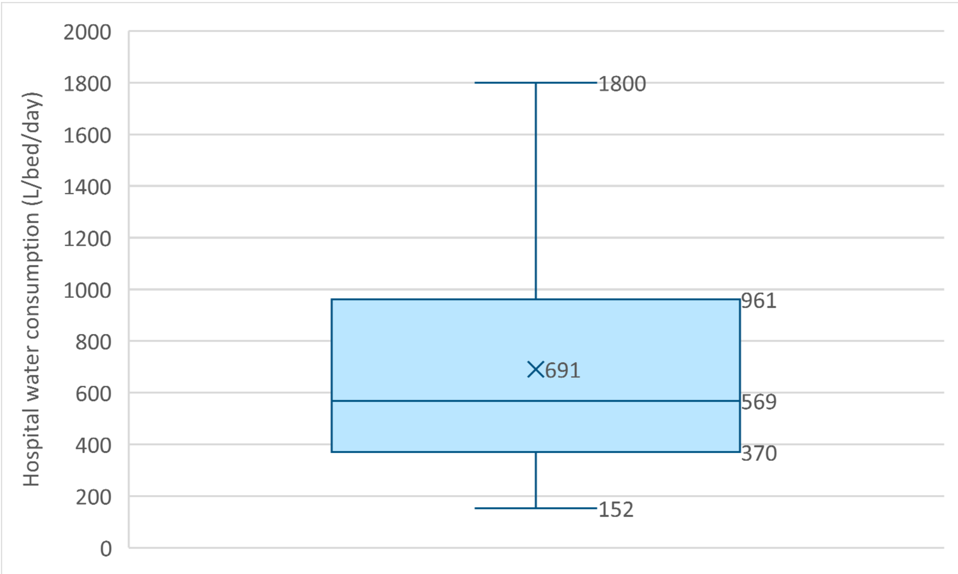


Figure 3 - 90 Distribution of daily per bed water consumption in hospital

The research found no previous work on the number of hospital beds and total consumption. Therefore, when developing this thesis, it was impossible to derive how the per bed water consumption may change depending on the number of beds in a hospital. In fact, none of the studies found included reliable data about the number of beds in the hospital.

Unfortunately, hospitals' water consumption with their number of beds is not available when developing the theses. Consequently, the correlation between hospital water consumption per bed and the number of beds cannot be visualized. So, this unitary water consumption needs further analysis and investigation.

3.3.8.3 Hospital water consumption findings

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of hospital water consumption is due to the following reasons:

- Gleick et al. (2003) pointed out that some hospitals have in-house laundries, while others outsource their laundry. This could be one of the implications that causes a variation in water consumption.
- BIS and Cranfield University (2009) indicated that water consumption in hospitals relies on their buildings' physical characteristics and individual behaviour.
- Topbas et al. (2016) stated that water consumption in hospitals differs according to locations, ages, types of buildings, the number of patients and visitors, and the type and number of healthcare services provided. Moreover, the Hospital Energy Alliance (2011) added types and ages of plumbing equipment and practices toward water consumption.

3.3.9 Mosque water consumption

The mosque is a building where religious activities and Islamic worship are performed. Muslims are mandated to make ablutions or wash certain body parts as a condition for prayer (Al Mamun A et al., 2014). These ablutions typically consist of washing hands, face, mouth, nose, arms and swabbing on the head, ears, and feet (Roubi A. Zaied. 2017). Ablution is a compulsory religious action for Muslims repeated approximately five times daily for worshippers (Roubi A. Zaied. 2017).

Currently, worshippers use a significant amount of water in their ablutions. Different studies estimate the average amount of ablution water used across 42 mosques. The water consumption of more than 42 mosques was studied and analyzed. The study results showed the amount of water consumption estimated in each ablution between 3 L to 7 L/, equivalent to 15-21 L/worshipper/day (Abu Rozaiza 2002a).

In the two holy Harams, ablution water consumption is estimated to be 6 L/ablution to 7.5 L/ablution, equivalent to 30 L/worshipper/day to 37.5 L/worshipper/day (Abu Rozaiza 2002b).

The average water consumption in ablution was estimated to be between 2.5 L/ablution to 4.5 L/ablution, equivalent to the 12.5 L/worshipper/day range to 22.5 L/worshipper/day. This estimation increased to 5 L/ablution, equal to 25 L/worshipper/day (Abu Rozaiza 2002b).

In 2009, the Dubai Water and Electricity Authority (Dewa) and Sesam Business Consultants established a water conservation plan. The action plan decreased a mosque's water consumption from 5,749 L/day to 3,816 L/day (Emmanuelle Landais, 2010).

In 2013, Hisaar Foundation estimated the water consumption in the mosque as 14 L/worshipper/day, while mosque water consumption based on three ablution estimations as 5 L, 3 L, and 2 L, which is equivalent to 25 L/worshipper/day, 15 L/worshipper/day and 10 L/worshipper/day (Alzain, 2009).

The International Islamic University of Malaysia (IIUM) developed a study of water consumption in the Gombak Campus mosque, which has a capacity of 9,000 worshippers. The outcomes from this study showed that the mosque consumption was between 21,667 L/day to 25,000 L/day, equivalent to 7 L/worshipper/day (Al Mamun A et al., 2014).

In the Middle East and Arabian Gulf area, the average amount of water consumption in ablution was estimated to be 10 L/ablution, equivalent to 50 L/worshipper/day (Roubi A. Zaied. 2017).

Abu Dhabi Distribution Company (ADDC) calculated mosque water consumption to be 8.9 MCM in 2015, with an average consumption of 9,171 L/worshipper/day (Jochebed Menon, 2017).

3.3.9.1 Mosque water consumption micro-components analysis

Water consumption micro-components in the mosque were not available when developing this thesis; therefore, the best approach to determine the micro-components is through assumptions and comparisons. The water consumption in a mosque can be consumed in the restroom (including ablution), cooling and heating, and landscaping (including cleaning). There is no other way of water consumption in the mosque other than what has been defined. From the references analyzed, it can be estimated that cooling and heating average 0.9 L/m²/day (Figure 3 - 33) and 14% of the total water consumption (Figure 3 - 30), and irrigation was 3.5 L/m²/day (Figure 3 - 27) and 18% of the total water consumption (Figure 3 - 24). The percentage of water consumption in the restroom, including ablution, can be estimated at 68%, i.e., 100% minus 14% (the percentage of cooling and heating water consumption) and 18% (the percentage of irrigation water consumption).

3.3.9.2 Mosque water consumption distribution analysis

This analysis aims to determine the water consumption per worshipper in the mosque. Based on the data collected and analyzed from several studies (Emmanuelle Landais, 2010; Al Mamun A et al., 2014; Jochebed Menon, 2017), the distribution of mosque water consumption is shown in
Figure 3 - 91. From all the studies, the resulting average water consumed is 13,081 L/day. The remaining statistics are shown in the figure below.

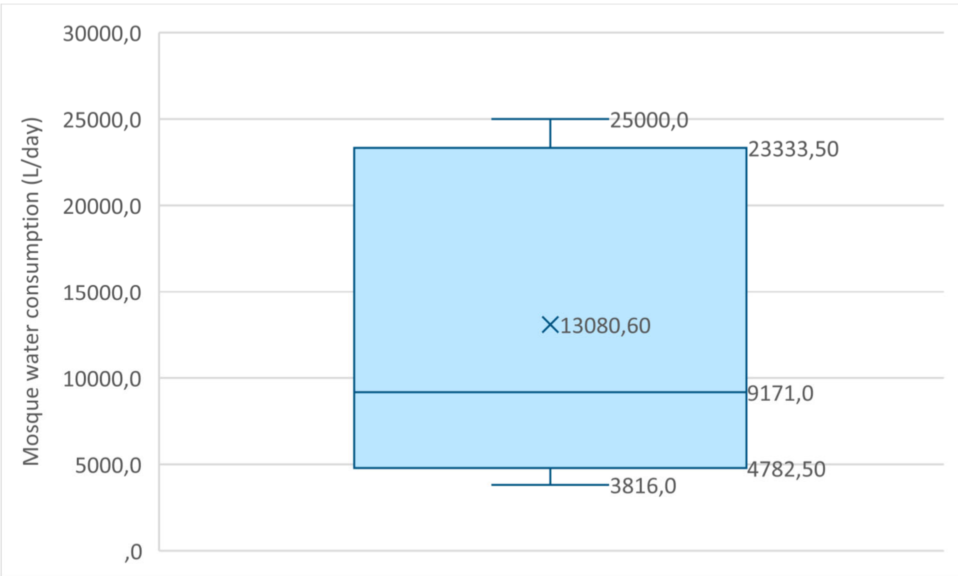


Figure 3 - 91 Distribution of daily water consumption in a mosque

3.3.9.2.1 Daily mosque water consumption based on the number of worshippers

The mosque water consumption per worshipper, considering the mosque's total number of worshippers, is shown in Figure 3 - 92, which presents the data collected and analyzed from several studies (Al Mamun A et al., 2014; Hisaar Foundation 2013; Abu Rozaiza 2002a; Abu Rozaiza 2002b; Roubi A. Zaied. 2017; Alzain 2009). From all the studies, the resulting average is 29 L/worshipper/day. The remaining statistics are shown in the figure below.

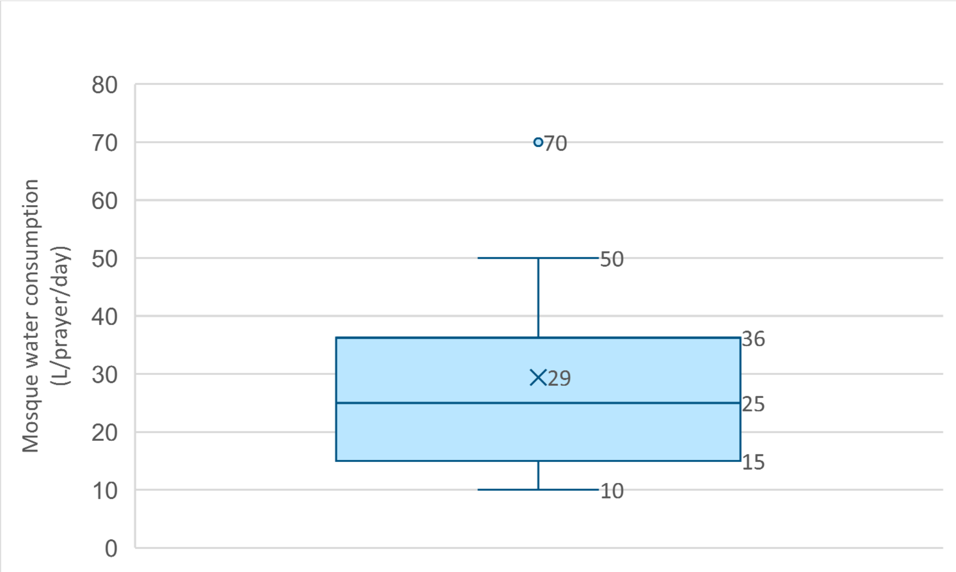


Figure 3 - 92 Distribution of daily per worshipper water consumption in a mosque

The research conducted did not find any previous work relating to the number of worshippers in a mosque with its total consumption. Therefore, when developing this thesis, it was impossible to derive how the per worshipper water consumption may change depending on the number of worshippers in a mosque. In fact, none of the studies found included reliable data about the number of worshippers in the mosque.

Unfortunately, mosques' water consumption with their number of worshippers is not available when developing the theses. Consequently, the correlation between mosque water consumption per worshipper and the number of worshippers cannot be visualized. So, this unitary water consumption needs further analysis and investigation.

3.3.9.3 Mosque water consumption findings.

Based on the analysis of data compiled and analyzed from previous studies, it is concluded that the variation in the amount of mosque water consumption is due to the following reasons:

- Surat Kon et al. (2014) mentioned that the tap (which has a different flow rate) is usually left running during the ablutions. This practice may indicate the reasons for the variation in the total water consumption in the mosques.
- Roubi A. Zaied. (2017) pointed out that tap design impacts water usage patterns in ablution. So, water consumption varies between mosques.

Chapter 4

MATHEMATICAL MODEL IN MUNICIPAL WATER CONSUMPTION

4 MATHEMATICAL MODELS IN MUNICIPAL WATER CONSUMPTION

4.1 Introduction

The municipal water models, divided into residential and non-residential water consumption, aim to provide tools that help assess water consumption patterns/trends and build a forecast without constraints. Different developments have been conducted in the municipal water model to specify their determinants, main drivers, and water consumption predictors. It can be used to obtain water consumption in different approaches depending on various data and scenarios availability.

As a result of the approach adopted, unitary consumption will be described as a function of water consumption predictors for each segment.

Obviously, each segment may have a different function and set of predictors that describe unitary consumption. The derivation of these functions is conducted by utilizing various statistical techniques for each of the micro-component consumption considered in each segment.

These functions constitute the water consumption model and allow the model to relate water consumption with several parameters/variables that describe the segment.

The main outcome of the municipal water model is:

- A bottom-up water model is based upon clear assumptions that can address various scenarios.

A summary of the process that followed to build the municipal water model is described in the following next steps:

jjj. Dependent variables are defined as the amount of water utilized in each segment. More precisely, and for the non-residential, the dependent variables considered, for example, in the restaurant: number of tables, restaurant size, and restaurant employees.

kkk. Independent variables that can explain the amount of water consumed are obtained by the detailed analysis of the water consumption micro-components in the segment.

lll. A detailed analysis conducted for each dependent variable consisted of checking the influence of every independent variable. Variables exerting a certain effect on the independent variable are called determinants. After this step, significant determinants for each independent variable will be identified.

mmm. The determinant variables that have been found to explain the dependent variables better are called predictors. Obviously, the number of predictors chosen for the model depends on the goodness of fit and how easy it will be to obtain each predictor's values and how reliable it will be. For example, if a set of predictors provide a better explanation of water consumption, but the value of this set of predictors is much more difficult to obtain than another set (easier to find but not good for explaining water consumption), it is probably more advisable to select the second set than the first one.

Each segment's actual number of users will be needed during the extrapolation process. Probably, this number cannot be directly obtained from the different sources' information and must be somehow estimated. Therefore, the total consumption figure will also be subject to this estimation error. This source of uncertainty will still be present.

Water consumption will be predicted on an average daily or yearly time frame. So, it is only designed to predict average water consumption over a period that makes average values valid. For this same reason, each variable is only analyzed on average yearly terms when exploring an independent variable's effect.

As a general assumption, water consumption requirements are associated with per unit consumption. However, a total count of the number of units of each water consumer category is needed. This is true at present and for a 25 years projection; therefore, forecasts of population and building stock are an integral building block of the forecast.

4.2 Residential Water Consumption Models

The analysis of water consumption in residential areas comprises occupant number and outdoor or irrigation area in the housing unit analyzed in sections 3.3.2 and 3.3.3.

For the analysis to be meaningful and obtain comparable figures between different studies and residential, the average water consumption is analyzed in terms of a potential driver's unit. The drivers used to describe normalized water consumption in residential areas are occupant number and outdoor or irrigation area in a housing unit. Details of this analysis can be found in section (3.3.4). In any case, it should be highlighted that there is a large heterogeneity of water consumption in residential areas, as seen from the high variability of results described by the different authors referenced in the present Thesis.

With the data compiled and consolidated from several studies, more detailed relationships and conclusions can be raised to improve the development of a water consumption model in residential.

4.2.1 Residential water consumption unitary ratio parameters

Table 4 - 4 shows the average weight of each water consumption from all the studies considered in this analysis. This table summarizes the findings and has helped develop simplified and easy-to-use equations describing residential water consumption.

This table also shows the average residential daily water consumption ratio expressed in terms of the driver found in previous literature: household occupants' numbers, outdoor or irrigation area, and the per capita water consumption ratio.

Table 4 - 1 Different average ratios of per capita and outdoor or irrigation water consumption use based on housing units with different occupant numbers

Occupant number in housing unit.	**One person**	**Two people**	**Three people**	**Four people**	**Five people**	**Six people and more**
The average ratio of per capita water consumption.	0.0	-0.12	-0.21	-0.28	-0.35	-0.41
Outdoor or irrigation water consumption as a ratio of residential use.	0.31	0.27	0.22	0.16	0.10	0.06

4.2.2 Residential water consumption model assumptions

From Table 4 - 1, the following equations can be derived based on the assumption that residential water consumption can be obtained as a function of the main drivers previously mentioned: occupant number, outdoor and/or irrigation area. The residential water consumption models must reflect the influence of these drivers and their contribution to water consumption in the housing unit.

Residential water consumption consists of different micro-components, as discussed in detail in section (3.3.3). Considering the previously mentioned drivers, it seems reasonable to assume that water consumption due to irrigation should only be related to their coverage area. Therefore, if the irrigation area (IA) is known, the water consumption of these components can be easily determined utilizing the average daily water consumption in the irrigation area (IA) - 3.5 L/m²/day (Figure 3 - 27). But, if the irrigation area (IA) is unknown, it can be estimated as a ratio of residential use.

4.2.3 Daily residential water consumption equations

Daily residential water consumption equations can be developed based on housing units' number with their occupants' number, and the per capita water consumption when outdoor or irrigation area is known and unknown.

4.2.3.1 Daily residential water consumption equations based on the number of houses, occupancy and per capita when irrigation area is known

1. Total Residential Water Consumption (TRWC) based on the Number of Houses (NH), its occupants' number (i) and Per Capita water consumption when the Irrigation Area (IA) is known

$$TRWC_{\mathrm{i}} = Per\ Cap \cdot (1 + C_{\mathrm{i}}) \cdot (NH_{\mathrm{i}}) + C_{IA} \cdot (IA_{\mathrm{i}})$$

Where:

- *The subindex (i) represents the number of occupants in the housing units.*
- C_i *represents the per capita consumption ratio for occupancy of (i), as expressed in Table 4 - 2*
- $Per\ Cap.$ *is the per capita water consumption.*
- NH_i *is the number of houses based on household occupants (i).*
- IA_i *is Irrigation Area in houses based on household occupants (i).*

Table 4 - 2 Unitary residential water consumption based on the number of houses with household members and per capita when irrigation area is known

Coefficient Name	Definition	Value	Unit	Reference
C_{i}	The average per capita water consumption ratio is based on the housing unit's number of household occupants (i).	C_1= 0 C_2= -0.12 C_3= -0.21 C_4= -0.28 C_5= -0.35 $C_{>=6}$= -0.41	-	(Table 4 - 1)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

4.2.3.2 Daily residential water consumption equations based on the number of houses with their occupants' number and per capita when the irrigation area is unknown

1. Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with its occupants' number (i) and Per Capita water consumption when Irrigation Area (IA) is unknown

$$TRWC_{\mathrm{i}} = Per\ Cap.\cdot NH_{\mathrm{i}}\cdot((1 + C_{\mathrm{i}}). + C_{IOA-i})$$

Where:

- *The subindex (i) represents the number of occupants in housing units based on the parameters expressed in Table 4 - 3.*
- $Per\ Cap.$ *is the per capita water consumption.*
- NH_i *is the number of houses based on household occupants (i).*

Table 4 - 3 Unitary residential water consumption-based numbers of houses with household members and per capita, when irrigation area is known

Coefficient Name	**Definition**	**Value**		**Unit**	**Reference**
C_{i}	The average per capita water consumption ratio is based on the housing unit's number of household occupants (i).	i=1 i=2 I =3 i=4 i=5 i>=6	C_i= 0 C_i= -0.12 C_i= -0.21 C_i= -0.28 C_i= -0.35 C_i= -0.41	-	(Table 4 - 1)
$\mathrm{C}_{\mathrm{IOA-i}}$	The water consumption ratio in irrigation or outdoor area is based on an occupancy of (i) occupants of the housing unit.	i=1 i=2 I =3 i=4 i=5 i>=6	C_{IOA-i}= 0.31 C_{IOA-i}= 0.27 C_{IOA-i}= 0.22 C_{IOA-i}= 0.16 C_{IOA-i}= 0.10 C_{IOA-i}= 0.06	-	(Figure 3 - 27)

4.3 Non-Residential Water Consumption Models

After analyzing non-residential water consumption breakdown and daily water consumption based on different unitary approaches for each customer category, further analysis and links can be obtained to build relevant unitary water consumption equations.

4.3.1 Hotels

The analysis of hotel water consumption comprises seven main micro-components: guest room consumption, irrigation, cooling and heating, kitchen, swimming pool, laundry, and a final component, including all other non-considered uses and any unintentional consumption. These are analyzed in section (3.4.1.1).

For the analysis to be meaningful and obtain comparable figures between different studies and hotels, the average water consumption is analyzed in terms of a potential driver's unit. The drivers used to describe normalized water consumption in hotels are the floor area, the number of guests, and the rooms. Details of this analysis can be found in section (3.4.1.3). In any case, the large heterogeneity of water consumption in hotels should be highlighted, as seen from the high variability of results described by the different authors referenced in the present thesis.

More detailed relationships and conclusions can be raised through the data compiled and consolidated from several studies, enabling the development of hotels' water consumption models.

4.3.1.1 Water consumption micro-components in hotels

Table 4 - 4 shows the average weight of each water consumption micro-component from all the studies considered in this analysis. This table summarizes the findings and has helped develop simplified and easy-to-use equations describing hotel water consumption.

As a result, the sum of the different micro-components average contribution does not necessarily have to add up exactly 100%. This is because the average contribution specified for a given micro-component (second row in Table 4 - 4) is calculated from the various contributions of all previous studies. In the case of hotels, the sum of the contributions of the different uses sums up to 107%. Therefore, the average figures must be normalized, so all micro-components' aggregated contribution is precisely 100%. The normalized values of these contributions are presented in row 3.

This table also shows the average daily water consumption in the hotels based on the various drivers found in previous literature, as expressed in terms of the floor area, the number of guests, and the number of rooms.

The normalized figures obtained for each one of these drivers are the following:

- The average daily water consumption per floor area figure is 6.89 L/m2/day, obtained and calculated through a frequency distribution analysis of the data extracted from the different studies (Figure 3 - 39).
- In the same manner, it has been obtained that the average value for the Distribution of daily per guest water consumption in a hotel (Figure 3 - 42).
- Finally, it has been derived that the average Distribution of daily per room water consumption in a *hotel* (Figure 3 - 45).

Table 4 - 4 Contribution of water consumption micro-components in hotels. Average figures and benchmarks

Hotel water consumption micro-components and its unitary parameters.	**Guest room**	**Irrigation**	**Cooling and heating**	**Kitchen**	**Other**	**pool**	**Laundry**	**Total**
Percentage of water consumption micro-components.	34%	8%	15%	17%	16%	3%	14%	107%
Modified percentage of water consumption micro-components.	32%	7%	14%	16%	15%	3%	13%	100%
Average daily water consumption, based on the floor area (L/m^2/day).	2.19	0.52	1.0	1.09	1.03	0.19	0.90	6.89
Average daily water consumption, based on the number of guests (L/guest/day).	218	51	96	109	103	19	90	686
The average daily water consumption is based on the number of rooms (L/room/day).	312	73	138	156	147	28	128	981

4.3.1.2 Model assumptions in describing water consumption in hotels

From Table 4 - 4, the following equations can be derived based on the assumption that hotel water consumption can be obtained as a function of the main drivers previously mentioned: the floor area, the number of guests, and the number of rooms. The influence of these drivers and their contribution to water consumption in a hotel must be reflected in the hotels' water consumption models.

Hotel water consumption consists of different micro-components, as discussed in sections 3.4.1.1 and 3.4.1.2. Considering the previously mentioned drivers, it seems reasonable to assume that the water consumption due to irrigation, cooling, and heating should only be related to their coverage area. Therefore, if the irrigation area (IA) and cooling and heating area (CHA) are known, the water consumption of these components can be easily determined. This way, the average daily water consumption in the cooling and heating area (CHA) - 0.9 L/m²/day (Figure 3 - 33) - and the average daily water consumption in the irrigation area (IA) - 3.5 L/m²/day (Figure 3 - 27), should be taken into account. But, if the irrigation area (IA) and the cooling and heating area (CHA) are unknown, the water consumption of these uses needs to be estimated as a function ratio in terms of other drivers' expression functions.

4.3.1.3 Daily hotel water consumption equations

Daily hotel water consumption equations can be developed based on the floor area (FA), the number of guests (NG) and the number of rooms (NR), either if the cooling and heating area (CHA) or irrigation area (IA) are known and unknown or cannot be estimated.

4.3.1.3.1 Daily hotel water consumption equations based on the floor area

1. *Total Water Consumption (TWC) in the hotel is based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{\mathrm{hotel}} = C_{FA} \cdot FA + C_{CHA} \cdot (\mathrm{CHA}) + C_{IA} \cdot (\mathrm{IA})$$

Where:

- *C_{XXX} coefficients, where the subindex C_{FA}, C_{CHA}, and C_{IA} represents the average unitary hotel water consumption based on the parameters expressed in Table 4 - 5.*

Table 4 - 5 Unitary hotel water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
$\mathrm{C_{FA}}$	The average unitary hotel water consumption based on the floor area. This consumption includes guestrooms, kitchen, other consumptions, swimming pool, and laundry.	5.41	L/m^2/day	(Table 4 - 4)
$\mathrm{C_{CHA}}$	The average unitary water consumption in cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
$\mathrm{C_{IA}}$	The average unitary water consumption in irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *FA is the hotel's floor area, calculated from the equations based on available parameters.*

  FA = NG $\cdot \mathrm{R_{NG}^{FA}}$

  FA = NR $\cdot \mathrm{R_{NR}^{FA}}$

- *CHA is the cooling and heating area in the hotel.*
- *IA is the irrigation area in the hotel.*
- *R_{YY}^{XX} coefficient ratio, where the subindex YY and subindex XX represents the hotel water consumption (Table 4 - 4) based on the parameters expressed in Table 4 - 6.*

Table 4 - 6 Ratio of hotel water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{NG}^{FA}	Ratio representing water consumption based on the number of guests to water consumption based on the hotel floor area. This consumption includes guestrooms, kitchen, others/unaccounted, pool, and laundry.	100	m²/guest
R_{NR}^{FA}	Ratio representing water consumption based on the number of rooms to water consumption based on the hotel floor area. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	142	m²/room

2. *Total Water Consumption (TWC) in the hotel based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{hotel} = FA \cdot (C_{FA} + C_{CHA,U} + C_{IA,U})$$

Where:

- *C_{XXXX} coefficients where the subindex C_{FA}, $C_{CHA,U}$ and $C_{IA,U}$ represents unitary hotel water consumption based on the parameters expressed in Table 4 - 7.*

Table 4 - 7 Unitary hotel water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	1	L/m²/day	(Table 4 - 4)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	0.5	L/m²/day	(Table 4 - 4)

3. *Total Water Consumption (TWC) in the hotel based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{hotel} = C_{FA,T} \cdot FA$$

Where:

- *FA is the floor area in the hotel and can be calculated from the above equations based on available parameters.*
- *$C_{FA,T}$ is a total unitary hotel water consumption based on the hotel floor area. From the analyzed references, it can be estimated as 6.89 L/m²/day (Table 4 - 4).*

4.3.1.3.2 Daily hotel water consumption equations based on the number of guests

1. *Total Water Consumption (TWC) in the hotel based on the Number of Guests (NG) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{hotel} = NG \cdot (C_{NG} + C_{CHA} \cdot (1/R_{CHA}^{NG}) + C_{IA} \cdot (1/R_{IA}^{NG}))$$

Where:

– C_{XXX} coefficients, coefficients, where the subindex C_{NG}, C_{CHA} and C_{IA} represents the average unitary hotel water consumption based on the parameters expressed in Table 4 - 8.

Table 4 - 8 Unitary hotel water consumption based on the number of guests when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NG}	The average unitary hotel water consumption based on the number of guests. This consumption includes guestrooms, kitchen, others/unaccounted, swimming pool, and laundry.	539	L/capita/day	(Table 4 - 4)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m²/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m²/day	(Figure 3 - 27)

– *NG is the number of guests in the hotel; and can be calculated from the equations based on available parameters.*

NG = $FA \cdot R_{FA}^{NG}$
NG = $NR \cdot R_{NR}^{NG}$

– *CHA is the cooling and heating area in the hotel.*

– *IA is the irrigation area in the hotel.*

– *R_{YYY}^{XX} coefficient ratio, where the subindex YYY and subindex XX represents the hotel water consumption (Table 4 - 4), based on the parameters expressed in Table 4 - 9.*

Table 4 - 9 Ratio of hotel water consumption based on the number of guests when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{FA}^{NG}	Ratio representing water consumption based on the hotel floor area to water consumption based on the number of guests. This consumption includes guestrooms, kitchen, others/unaccounted, swimming pool, and laundry.	0.01	guest/m^2
R_{NR}^{NG}	Ratio representing water consumption based on the number of rooms to water consumption based on the number of guests. This consumption includes guestrooms, kitchen, others/unaccounted, swimming pool, and laundry.	1.4	guest/room
R_{CHA}^{NG}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of cooling and heating area based on the number of guests when its area is known.	0.04	guest/m^2
R_{IA}^{NG}	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the number of guests when its area is known.	0.018	guest/m^2

2. *Total Water Consumption (TWC) in the hotel based on the number of guests (NG) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{hotel} = NG\cdot(C_{NG} + C_{CHA,U}\cdot(1/R^{NG}_{CHA,U}) + C_{IA,U}\cdot(1/R^{NG}_{IA,U}))$$

Where:

– *C_{XXXX} coefficients where the subindex C_{NG}, $C_{CHA,U}$ and $C_{IA,U}$ represents the unitary hotel water consumption based on the parameters expressed in Table 4 - 10.*

Table 4 - 10 Unitary hotel water consumption based on the number of guests when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	**Definition**	**Value**	**Unit**	**Reference**
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	1	$L/m^2/day$	(Table 4 - 4)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	0.52	$L/m^2/day$	(Table 4 - 4)

– *R^{XX}_{YYYY} coefficient ratio, where the subindex YYYY and subindex XX represent hotel water consumption (Table 4 - 4), is based on the parameters expressed in Table 4 - 11.*

Table 4 - 11 Ratio of hotel water consumption based on the number of guests when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	**Definition**	**Value**	**Unit**
$R^{NG}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the hotel floor area to water consumption of the cooling and heating area based on the number of guests when its area is unknown.	0.01	$guest/m^2$
$R^{NG}_{IA,U}$	Ratio representing water consumption of the irrigation area based on the hotel floor area to water consumption of the irrigation area based on the number of customers when its area is unknown.	0.01	$guest/m^2$

3. *Total Water Consumption (TWC) in the hotel based on the Number of guests (NG) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{hotel} = C_{NG,T} \cdot NG$$

Where:

- NG *is the number of guests in a hotel; and can be calculated from the above equations based on available parameters.*
- $C_{NG,T}$ *is the total unitary hotel water consumption based on the number of guests. From analyzed references, it can be estimated as 686 L/guest/day (Table 4 - 4).*

4.3.1.3.3 Daily hotel water consumption equations-based number of guests, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the hotel based on the Number of Guests (NG), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{hotel} = C_{NG} \cdot NG + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

- C_{XXX} *coefficients, where the subindex* C_{NG}, C_{CHA} *and* C_{IA} *represents the average unitary hotel water consumption based on the parameters expressed in Table 4 - 12.*

Table 4 - 12 Unitary hotel water consumption based on the number of guests, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{NG}	The average unitary hotel water consumption based on the number of guests. This consumption includes guestrooms, kitchen, others/ unaccounted, swimming pool, and laundry.	539	L/capita/day	(Table 4 - 4)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- NG *is the number of guests in the hotel.*
- CHA *is the cooling and heating area in the hotel.*
- IA *is the irrigation area in the hotel.*

4.3.1.3.4 Daily hotel water consumption equations based on the number of rooms

1. *Total Water Consumption (TWC) in the hotel based on the Number of Rooms (NR) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{hotel} = NR \cdot (C_{NR} + C_{CHA} \cdot (1/R^{NR}_{CHA}) + C_{IA} \cdot (1/R^{NR}_{IA}))$$

Where:

- C_{XXX} *coefficients, where the subindex* C_{NR}, C_{CHA} *and* C_{IA} *represents the average unitary hotel water consumption based on the parameters expressed in Table 4 - 13.*

Table 4 - 13 Unitary hotel water consumption based on the number of rooms when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NR}	The average unitary hotel water consumption based on the number of rooms. This consumption includes guestrooms, kitchen others/ unaccounted, swimming pool, and laundry.	770	L/room/day	(Table 4 - 4)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *NR is the number of employees in the hotel; and can be calculated from the equations based on available parameters.*

  NR =$FA \cdot R^{NR}_{FA}$
  NR= $NG \cdot R^{NR}_{NG}$
- CHA *is the cooling and heating area in the hotel.*
- *IA is the irrigation area in the hotel.*
- R^{XX}_{YYY} *coefficient ratio, where the subindex YYY and subindex XX represents the hotel water consumption (Table 4 - 4), based on the parameters expressed in Table 4 - 14.*

Table 4 - 14 Ratio of hotel water consumption based on the number of rooms when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{FA}^{NR}	Ratio representing water consumption based on the hotel floor area to the water consumption based on the number of rooms. This consumption includes guestrooms, kitchen, others/unaccounted, swimming pool, and laundry.	0.007	room/m^2
R_{NG}^{NR}	Ratio representing water consumption based on the number of guests to the water consumption based on the number of rooms. This consumption includes guestrooms, kitchen, others/unaccounted, swimming pool, and laundry.	0.7	room/guest
R_{CHA}^{NR}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the number of rooms when its area is known.	0.026	room/m^2
R_{IA}^{NR}	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the number of rooms when its area is known.	0.01	room/m^2

2. *Total Water Consumption (TWC) in the hotel based on the Number of Rooms (NR) when Cooling and Heating area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{hotel} = NR \cdot (C_{NR} + C_{CHA,U} \cdot (1/R_{CHA,U}^{NR}) + C_{IA,U} \cdot (1/R_{IA,U}^{NR}))$$

Where:

– *C_{XXXX} coefficients where the subindex C_{NR}, $C_{CHA,U}$ and $C_{IA,U}$ represents the unitary hotel water consumption based on the parameters expressed in Table 4 - 15.*

Table 4 - 15 Unitary hotel water consumption based on the number of rooms when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	1	L/m^2/day	(Table 4 - 4)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	0.5	L/m^2/day	(Table 4 - 4)

– R_{YYYY}^{XX} *coefficient ratio, where the subindex YYYY and subindex XX represents the hotel water consumption (Table 4 - 4), based on the parameters expressed in Table 4 - 16.*

Table 4 - 16 Ratio of hotel water consumption based on the number of rooms when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$\mathrm{R}_{\mathrm{CHA,U}}^{\mathrm{NR}}$	Ratio representing water consumption of the cooling and heating area based on the floor area to water consumption of the cooling and heating area based on the number of rooms when its area is unknown.	0.007	room/m^2
$\mathrm{R}_{\mathrm{IA,U}}^{\mathrm{NR}}$	Ratio representing water consumption of the irrigation area based on its area to water consumption of the irrigation area based on the number of rooms when its area is unknown.	0.01	room/m^2

3. *Total Water Consumption (TWC) in the hotel based on the Number of Rooms (NR) when Cooling and Heating area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{hotel} = C_{NR,T} \cdot NR$$

Where:

– NR *is the number of rooms in the hotel; and can be calculated from the above equations based on available parameters.*

– $C_{NR,T}$ *is total unitary hotel water consumption based on the number of rooms. The analyzed references estimate it as 981 L/room/day (Table 4 - 4).*

4.3.1.3.5 Daily hotel water consumption equations based on the number of rooms, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the hotel based on the Number of Rooms (NR), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{hotel} = C_{NR} \cdot NR + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

- C_{XXX} *coefficients, where the subindex* C_{NR}*,* C_{CHA} *and* C_{IA} *represents the average unitary hotel water consumption based on the parameters expressed in Table 4 - 17.*

Table 4 - 17 Unitary hotel water consumption based on the number of rooms, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{NR}	The average unitary hotel water consumption based on the number of rooms. This consumption includes guestrooms, kitchen, others/ unaccounted, swimming pool, and laundry.	770	L/room/day	(Table 4 - 4)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *NR is the number of employees in the hotel.*
- CHA *is the cooling and heating area in the hotel.*
- IA *is the irrigation area in the hotel.*

4.3.2 Restaurants

The analysis of water consumption in restaurants comprises five main micro-components, namely restroom consumption, irrigation, cooling and heating, kitchen and a final component which includes all other non-considered uses and any unintentional consumption. These water consumption micro-components are analyzed in section (3.4.2.1).

For the analysis to be meaningful and to obtain comparable figures between different studies and restaurants, the average water consumption is analyzed in terms of a unit of a potential driver. More specifically, the drivers used to describe normalized water consumption in restaurants are the floor area, the number of customers, the number of employees, the number of seats and the number of meals. Details of this analysis can be found in section (3.4.2.2). In any case, the large heterogeneity of water consumption in restaurants should be highlighted, as seen from the high variability of results described by the different authors referenced in the present thesis.

With the data compiled and consolidated from several studies, more detailed relationships and conclusions can be raised to improve the development of a restaurant water consumption model.

4.3.2.1 Water consumption micro-components in restaurants

Table 4 - 18 shows the average weight of each water consumption micro-component from all the studies considered in this analysis. This table summarizes the findings and has helped develop simplified and easy to use equations that describe water consumption in restaurants.

As a result, the sum of the different micro-components' average contribution does not necessarily have to add up exactly 100%. This is because the average contribution specified for a given micro-component (second row in Table 4 - 18) is calculated from the various contributions of all previous studies. In the case of restaurants, the sum of the contributions of the different uses sums up to 102%. Therefore, the average figures must be normalized, so all micro-components' aggregated contribution is precisely 100%. The normalized values of these contributions are presented in row 3.

This table also shows the average daily water consumption in the restaurants based on the various drivers found in previous literature, as expressed in terms of the floor area, the number of customers, the number of employees, the number of seats, and the number of meals.

The normalized figures obtained for each one of these drivers are the following:

- The average figure for the daily water consumption per floor area is 30 L/m^2/day, obtained and calculated through a frequency distribution analysis of the data extracted from the different studies (Figure 3 - 50).
- In the same manner, it has been obtained that the average value for daily water consumption in restaurants per customer is 41 L/customer/day (Figure 3 - 53).

- It has also been obtained that the average value for daily water consumption in restaurants per employee is 485 L/employee /day (Figure 3 - 56).
- Also, it has been obtained that the average value for daily water consumption in restaurants per seat is 158 L/seat/day (Figure 3 - 57).
- Finally, it has been derived that the average daily water consumption per meal is 27 L/meal /day (Figure 3 - 58).

Table 4 - 18 Contribution of water consumption micro-components in restaurants. Average figures and benchmarks

Restaurant water consumption micro-components and its unitary parameters.	**Kitchen**	**Restrooms**	**Other**	**Landscape**	**Cooling and heating**	**Total**
Average percentage of water consumption micro-components.	50%	32%	13%	5%	2%	102%
Percentage of water consumption micro-components.	49%	31%	13%	5%	2%	100%
Average daily water consumption, based on the floor area (L/m^2/day).	14.7	9.3	3.9	1.5	0.6	30
Average daily water consumption, based on the number of customers (L/customer/day).	20.1	12.7	5.3	2.1	0.8	41
Average daily water consumption, based on the number of employees (L/employee/day).	237.7	150.4	63.1	24.3	9.7	485
Average daily water consumption, based on the seat number (L/seat/day).	77.4	49.0	20.5	7.9	3.2	158
Average daily water consumption, based on the number of meals (L/meal/day).	13.2	8.4	3.5	1.4	0.5	27

4.3.2.2 Model assumptions in describing water consumption in restaurants

From Table 4 - 18, the following equations can be derived based on the assumption that restaurant water consumption can be obtained as a function of the main drivers previously mentioned: floor area of the restaurant, number of customers, number of employees, number of seats and number of meals. The influence of these drivers and how their contribution may affect water consumption in a restaurant must be reflected in the restaurant water model to be applied.

Restaurant water consumption consists of different micro-components, as discussed in detail in section (3.4.2.1). Considering the previously mentioned drivers, it seems reasonable to assume that the water consumption due to irrigation, cooling, and heating should only be related to their coverage area. Therefore, if the irrigation area (IA) and cooling and heating area (CHA) are known, the water consumed by these components can be determined through the average daily water consumption in the cooling and heating area (CHA) – 0.9 $L/m^2/day$ (Figure 3 - 33) – and the average daily water consumption in irrigation area (IA) –3.5 $L/m^2/day$ (Figure 3 - 27). But, if the irrigation area (IA) and the cooling and heating area (CHA) are unknown, the water consumption of these uses needs to be estimated as a function ratio in terms of other drivers' expression functions.

4.3.2.3 Daily restaurant water consumption equations

Daily restaurant water consumption equations can be developed based on five unitary factors, which are the floor area (FA), the number of employees (NE), the number of customers (NC), the number of seats (NS), or the number of meals served (NM), when cooling and heating area (CHA) and irrigation area (IA) are known and unknown or cannot be estimated.

4.3.2.3.1 Daily restaurant water consumption equations based on the floor area

1. *Total Water Consumption (TWC) in the restaurant based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{restaurant} = C_{FA} \cdot FA + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

- C_{XXX} *coefficients, where the subindex* C_{FA}, C_{CHA} *and* C_{IA} *represents the average unitary restaurant water consumption based on the parameters expressed in Table 4 - 19.*

Table 4 - 19 Unitary restaurant water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{FA}	The average unitary restaurant water consumption based on the floor area. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	27.9	$L/m^2/day$	(Table 4 - 18)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	$L/m^2/day$	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	$L/m^2/day$	(Figure 3 - 27)

- *FA is the restaurant's floor area, calculated from the equations based on available parameters.*

  $FA = NE \cdot R_{NE}^{FA}$

  $FA = NC \cdot R_{NC}^{FA}$

  $FA = NS \cdot R_{NS}^{FA}$

  $FA = NM \cdot R_{NM}^{FA}$

- R_{YY}^{XX} *coefficient ratio, where the subindex YY and subindex XX represents the restaurant water consumption (Table 4 - 18), based on the parameters expressed in Table 4 - 20.*

Table 4 - 20 Ratio of restaurant water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{NE}^{FA}	Ratio representing water consumption based on the number of employees to water consumption based on the restaurant floor area. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	1.37	m^2/employee
R_{NC}^{FA}	Ratio representing water consumption based on the number of customers to water consumption based on the restaurant floor area. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	16.17	m^2/customer
R_{NS}^{FA}	Ratio representing water consumption based on the number of seats to water consumption based on the restaurant floor area. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	5.27	m^2/seat
R_{NM}^{FA}	Ratio representing water consumption based on the number of meals to water consumption based on the restaurant floor area. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.9	m^2/meal

2. *Total Water Consumption (TWC) in the restaurants based on Floor Area (FA) when Cooling and Heating area (CHA) and Irrigation area (IA) are unknown*

$$TWC_{restaurant} = C_{FA} \cdot FA + C_{CHA,U} \cdot (FA) + C_{IA,U} \cdot (FA)$$

Where:

- *C_{XXXX} coefficients where the subindex C_{FA}, $C_{CHA,U}$ and $C_{IA,U}$ represents the unitary restaurant water consumption based on the parameters expressed in Table 4 - 21.*

Table 4 - 21 Unitary restaurant water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.6	L/m^2/day	(Table 4 - 18)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	1.5	L/m^2/day	(Table 4 - 18)

3. *Total Water Consumption (TWC) in the restaurants based on Floor Area (FA) when the Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{restaurant} = C_{FA,T} \cdot FA$$

Where:

- *FA is the restaurant's floor area, calculated from the above equations based on available parameters.*
- $C_{FA,T}$ *is total unitary restaurant water consumption based on restaurant floor area. From the analyzed reference, it can be estimated as 30 L/m²/day (Table 4 - 18).*

4.3.2.3.2 Daily restaurant water consumption equations based on the number of customers

1. *Total Water Consumption (TWC) in the restaurant based on the Number of Customers (NC) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{restaurant} = NC \cdot (C_{NC} + C_{CHA} \cdot (1/R_{CHA}^{NC}) + C_{IA} \cdot (1/R_{IA}^{NC}))$$

Where:

- *C_{XXX} coefficients, where the subindex C_{NC}, C_{CHA} and C_{IA} represents the average unitary restaurant water consumption based on the parameters expressed in Table 4 - 22.*

Table 4 - 22 Unitary restaurant water consumption based on the number of customers when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NC}	The average unitary restaurant water consumption based on the number of customers. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	38.1	L/customer/day	(Table 4 - 18)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *NC is the number of customers in the restaurant and can be calculated from the equations based on available parameters.*

  NC $= FA \cdot R_{FA}^{NC}$
  NC$= NE \cdot R_{NE}^{NC}$
  NC$= NS \cdot R_{NS}^{NC}$
  NC$= NM \cdot R_{NM}^{NC}$

- *R_{YYY}^{XX} coefficient ratio, where the subindex YYY and subindex XX represents the restaurant water consumption (Table 4 - 18), based on the parameters expressed in Table 4 - 23.*

Table 4 - 23 Ratio of restaurant water consumption based on the number of customers when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	**Definition**	**Value**	**Unit**
R_{FA}^{NC}	Ratio representing water consumption based on the restaurant floor area to water consumption based on the number of customers. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.73	customer/m^2
R_{NE}^{NC}	Ratio representing water consumption based on the number of employees to water consumption based on the number of customers. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	11.83	customer/employee
R_{NS}^{NC}	Ratio representing water consumption based on the number of seats to water consumption based on the number of customers. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	3.85	customer/seat
R_{NM}^{NC}	Ratio representing water consumption based on the number of meals to water consumption based on the number of customers. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.66	customer/meal
R_{CHA}^{NC}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the number of customers when its area is known.	1.1	customer/m^2
R_{IA}^{NC}	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the number of customers when its area is known.	1.63	customer/m^2

2. *Total Water Consumption (TWC) in the restaurant based on the Number of Customers (NC) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{restaurant} = NC \cdot (C_{NC} + C_{CHA,U} \cdot (1/R^{NC}_{CHA,U}) + C_{IA} \cdot (1/R^{NC}_{IA,U}))$$

Where:

- *C_{XXX} coefficients where the subindex C_{NC}, $C_{CHA,U}$ and $C_{IA,U}$ represents the unitary restaurant water consumption based on the parameters in Table 4 - 24.*

Table 4 - 24 Unitary restaurant water consumption based on the number of customers when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.6	L/m^2/day	(Table 4 - 18)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	1.5	L/m^2/day	(Table 4 - 18)

- *R^{XX}_{YYYY} coefficient ratio, where the subindex YYYY and subindex XX represent the restaurant water consumption (Table 4 - 18), based on the parameters expressed in Table 4 - 25.*

Table 4 - 25 Ratio of restaurant water consumption based on the number of customers when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R^{NC}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the restaurant floor area to water consumption of the cooling and heating area based on the number of customers when its area is unknown.	1.4	customer/m^2
$R^{NC}_{IA,U}$	Ratio representing water consumption of the irrigation area based on the restaurant floor area to water consumption of the irrigation area based on the number of customers when its area is unknown.	1.3	customer/m^2

3. *Total Water Consumption (TWC) in the restaurant based on the Number of Customers (NC) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{restaurant} = C_{NC,T} \cdot NC$$

Where:

- NC *is the number of customers in the restaurant; and can be calculated from the above equations based on available parameters.*
- $C_{NC,T}$ *is total unitary restaurant water consumption based on the number of customers. From the analyzed references, it can be estimated as 41 L/customer/day (Table 4 - 18).*

4.3.2.3.3 Daily restaurant water consumption equations based on the number of customers, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the restaurant based on the Number of Customers (NC), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{restaurant} = C_{NC} \cdot NC + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

– C_{XXX} *coefficients, where the subindex* C_{NC}, C_{CHA} *and* C_{IA} *represents the average unitary restaurant water consumption based on the parameters expressed in Table 4 - 26.*

Table 4 - 26 Unitary restaurant water consumption based on the number of customers, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{NC}	The average unitary restaurant water consumption based on the number of customers. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	38.1	L/customer/day	(Table 4 - 18)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

– *NC is the number of customers in the restaurant.*

– CHA *is the cooling and heating area in the restaurant.*

– IA *is the irrigation area in the restaurant.*

4.3.2.3.4 Daily restaurant water consumption equations based on the number of employees

1. *Total Water Consumption (TWC) in the restaurant based on the Number of Employees (NE) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{restaurant} = NE \cdot (C_{NE} + C_{CHA} \cdot (1/R_{CHA}^{NE}) + C_{IA} \cdot (1/R_{IA}^{NE}))$$

Where:

- *C_{XXX} coefficients, where the subindex C_{NE}, C_{CHA} and C_{IA} represents the average unitary restaurant water consumption based on the parameters expressed in Table 4 - 27.*

Table 4 - 27 Unitary restaurant water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NE}	The average unitary restaurant water consumption based on the number of employees. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	451	L/employee/day	(Table 4 - 18)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *NE is the number of employees in the restaurants; and can be calculated from the equations based on available parameters.*

  NE $= FA \cdot R_{FA}^{NE}$
  NE$= NC \cdot R_{NC}^{NE}$
  NE$= NS \cdot R_{NS}^{NE}$
  NE$= NM \cdot R_{NM}^{NE}$

– R_{YYY}^{XX} *coefficient ratio, where the subindex YYY and subindex XX represents the restaurant water consumption (Table 4 - 18), based on the parameters expressed in Table 4 - 28.*

Table 4 - 28 Ratio of restaurant water consumption based on the number of employees when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	**Definition**	**Value**	**Unit**
$\mathrm{R_{FA}^{NC}}$	Ratio representing water consumption based on the restaurant floor area to water consumption based on the number of customers. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.73	customer/m^2
$\mathrm{R_{NE}^{NC}}$	Ratio representing water consumption based on the number of employees to water consumption based on the number of customers. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	11.83	customer/employee
$\mathrm{R_{NS}^{NC}}$	Ratio representing water consumption based on the number of seats to water consumption based on the number of customers. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	3.85	customer/seat
$\mathrm{R_{NM}^{NC}}$	Ratio representing water consumption based on the number of meals to water consumption based on the number of customers. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.66	customer/meal
$\mathrm{R_{CHA}^{NE}}$	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the number of customers when its area is known.	1.1	customer/m^2
$\mathrm{R_{IA}^{NE}}$	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the number of customers when its area is known.	1.63	customer/m^2

2. *Total Water Consumption (TWC) in the restaurant based on the number of employees (NE) when Cooling and Heating area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{restaurant} = NE \cdot (C_{NE} + C_{CHA,U} \cdot (1/R^{NE}_{CHA,U}) + \; C_{IA,U} \cdot (1/R^{NE}_{IA,U}))$$

Where:

- C_{XXX} *coefficients where the subindex* C_{NE}, $C_{CHA,U}$ *and* $C_{IA,U}$ *represents the average unitary restaurant water consumption based on the parameters expressed in Table 4 - 29.*

Table 4 - 29 Unitary restaurant water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.6	$L/m^2/day$	(Table 4 - 18)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	1.5	$L/m^2/day$	(Table 4 - 18)

- R^{XX}_{YYYY} *coefficient ratio, where the subindex YYYY and subindex XX represents the restaurant water consumption (Table 4 - 18), based on the parameters expressed in Table 4 - 30.*

Table 4 - 30 Ratio of restaurant water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R^{NE}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the restaurant floor area to water consumption of the cooling and heating area based on the number of employees when its area is unknown.	1.4	employee/m^2
$R^{NE}_{IA,U}$	Ratio representing water consumption of the cooling and heating area based on the restaurant floor area to water consumption of the irrigation area based on the number of employees when its area is unknown.	1.3	employee/m^2

3. *Total Water Consumption (TWC) in the restaurant based on the number of employees (NE) when Cooling and Heating area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{restaurant} = C_{NE,T} \cdot NE$$

Where:

- NE *is the number of employees in the restaurant; and can be calculated from the equations above based on available parameters.*
- $C_{NE,T}$ *is total unitary restaurant water consumption based on the number of employees. From the analyzed references, it can be estimated as 485 L/employee/day (Table 4 - 18).*

4.3.2.3.5 Daily restaurant water consumption equations based on the number of employees, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the restaurant based on the number of employees (NE), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{restaurant} = C_{NE} \cdot NE + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

– C_{XXX} *coefficients where the subindex* C_{NE}, $C_{CHA,U}$ *and* $C_{IA,U}$ *represents the average unitary restaurant water consumption based on the parameters expressed in Table 4 - 31.*

Table 4 - 31 Unitary restaurant water consumption based on the number of employees, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{NE}	The average unitary restaurant water consumption based on the number of employees. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	451	L/employee/day	(Table 4 - 18)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

– *NE is the number of employees in the restaurant.*

– CHA *is the cooling and heating area in the restaurant.*

– IA *is the irrigation area in the restaurant.*

4.3.2.3.6 Daily restaurant water consumption equations based on the number of seats

1. *Total Water Consumption (TWC) in the restaurant based on the Number of Seats (NS) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{restaurant} = NS\cdot(C_{NS} + C_{CHA}\cdot(1/R_{CHA}^{NS}) \ + \ C_{IA}\cdot(1/R_{IA}^{NS}))$$

Where:

- C_{XXX} *coefficients where the subindex* C_{NS}, $C_{CHA,U}$ *and* $C_{IA,U}$ *represents the average unitary restaurant water consumption based on the parameters expressed in Table 4 - 32.*

Table 4 - 32 Unitary restaurant water consumption based on the number of seats when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NS}	The average unitary restaurant water consumption based on the number of seats. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	147	L/seat/day	(Table 4 - 18)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	$L/m^2/day$	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	$L/m^2/day$	(Figure 3 - 27)

- *NS is the number of seats in the restaurant; and can be calculated from the equations based on available parameters.*

  NS =$FA\cdot R_{FA}^{NS}$

  NS= $NC\cdot R_{NC}^{NS}$

  NS= $NE\cdot R_{NE}^{NS}$

  NS= $NM\cdot R_{NM}^{NS}$

- R_{YYY}^{XX} *coefficient ratio, where the subindex YYY and subindex XX represents the restaurant water consumption (Table 4 - 18), based on the parameters expressed in Table 4 - 33.*

Table 4 - 33 Ratio of restaurant water consumption based on the number of seats when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{FA}^{NS}	Ratio representing water consumption based on the restaurant floor area to water consumption based on the number of seats. This consumption ratio includes restrooms, kitchen and others/unaccounted consumption.	0.19	seat/m^2
R_{NE}^{NS}	Ratio representing water consumption based on the number of employees to water consumption based on the number of seats. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.26	seat/employee
R_{NC}^{NS}	Ratio representing water consumption based on the number of customers to water consumption based on the number of seats. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	3.07	seat/customer
R_{NM}^{NS}	Ratio representing water consumption based on the number of meals to water consumption based on the number of seats. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.17	seat/meal
R_{CHA}^{NS}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the number of seats when its area is known.	5.26	seat/m^2
R_{IA}^{NS}	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the number of seats when its area is known.	5.3	customer/m^2

2. *Total Water Consumption (TWC) in the restaurant based on the Number of Seats (NS) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{restaurant} = NS \cdot (C_{NS} + C_{CHA,U} \cdot (1/R^{NS}_{CHA,U}) + C_{IA} \cdot (1/R^{NS}_{IA,U}))$$

Where:

- C_{XXX} *coefficients where the subindex* C_{FA}, $C_{CHA,U}$ *and* $C_{IA,U}$ *represents the average unitary restaurant water consumption based on the parameters expressed in Table 4 - 34.*

Table 4 - 34 Unitary restaurants' water consumption based on the number of seats when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.6	$L/m^2/day$	(Table 4 - 18)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	1.5	$L/m^2/day$	(Table 4 - 18)

- R^{XX}_{YYYY} *coefficient ratio, where the subindex YYYY and subindex XXXX represents the restaurant water consumption (Table 4 - 18), based on the parameters expressed in Table 4 - 35.*

Table 4 - 35 Ratio of restaurant water consumption based on the number of seats when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R^{NS}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the restaurant floor area to water consumption of the cooling and heating area based on the number of seats when its area is unknown.	5.26	$seat/m^2$
$R^{NS}_{IA,U}$	Ratio representing water consumption of the irrigation area based on the restaurant floor area to water consumption of the irrigation area based on the number of seats when its area is unknown.	5.3	$seat/m^2$

3. *Total Water Consumption (TWC) in the restaurant based on the Number of Seats (NS) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{restaurant} = C_{NS,T} \cdot NS$$

Where:

- NS *is the number of seats in the restaurant; and can be calculated from the above equations based on available parameters.*
- $C_{NS,T}$ *is total unitary restaurant water consumption based on the number of seats. The analyzed references estimate it as 485 L/seat/day (Table 4 - 18).*

4.3.2.3.7 Daily restaurant water consumption equations based on the number of seats, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the restaurant based on the Number of Seats (NS), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{restaurant} = C_{NS} \cdot NS + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

– C_{XXX} *coefficients, where the subindex* C_{NS}, C_{CHA} *and* C_{IA} *represents the average unitary restaurant water consumption based on the parameters in Table 4 - 36.*

Table 4 - 36 Unitary restaurant water consumption based on the number of seats, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{NS}	The average unitary restaurant water consumption based on the number of seats. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	147	L/seat/day	(Table 4 - 18)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

– *NS is the number of seats in the restaurant.*

– CHA *is the cooling and heating area in the restaurant.*

– IA *is the irrigation area in the restaurant.*

4.3.2.3.8 Daily restaurant water consumption equations based on the number of meals

1. *Total Water Consumption (TWC) in restaurants based on the Number of Meals (NM) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{restaurant} = NM \cdot (C_{NC} + C_{CHA} \cdot (1/R_{CHA}^{NM}) + C_{IA} \cdot (1/R_{IA}^{NM}))$$

Where:

- C_{XXX} *coefficients, where the subindex* C_{NC}, C_{CHA} *and* C_{IA} *represents the average unitary restaurant water consumption based on the parameters expressed in Table 4 - 37.*

Table 4 - 37 Unitary restaurant water consumption based on the number of meals when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NM}	The average unitary restaurant water consumption based on the number of meals. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	25.1	L/meal/day	(Table 4 - 18)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *NS is the number of seats in the restaurant; and can be calculated from the equations based on the parameters available.*

  NS $= FA \cdot R_{FA}^{NS}$
  NS$= NC \cdot R_{NC}^{NS}$
  NS$= NE \cdot R_{NE}^{NS}$
  NS$= NM \cdot R_{NM}^{NS}$

- R_{YYY}^{XX} *coefficient ratio, where the subindex YYY and subindex XX represents the restaurant water consumption (Table 4 - 18), based on the parameters expressed in Table 4 - 38.*

Table 4 - 38 Ratio of restaurant water consumption based on the number of meals when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{FA}^{NM}	Ratio representing water consumption based on the restaurant floor area to water consumption based on the number of meals. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.19	meal/m^2
R_{NE}^{NM}	Ratio representing water consumption based on the number of employees to water consumption based on the number of meals. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.26	meal/employee
R_{NC}^{NM}	Ratio representing water consumption based on the number of customers to water consumption based on the number of meals. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	3.07	meal/customer
R_{NM}^{NM}	Ratio representing water consumption based on the number of meals to water consumption based on the number of seats. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.17	seat/meal
R_{CHA}^{NM}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the number of meals when its area is known.	5.26	meal/m^2
R_{IA}^{NM}	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the number of meals when its area is known.	5.3	meal/m^2

2. *Total Water Consumption (TWC) in restaurants based on the Number of Meals (NM) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{restaurant} = NM \cdot (C_{NS} + C_{CHA,U} \cdot (1/R^{NS}_{CHA,U}) + C_{IA} \cdot (1/R^{NS}_{IA,U}))$$

Where:

- *C_{XXX} coefficients where the subindex C_{NS}, $C_{CHA,U}$ and $C_{IA,U}$ represents the average unitary restaurant water consumption based on the parameters expressed in Table 4 - 39.*

Table 4 - 39 Unitary restaurants' water consumption based on the number of meals when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.6	L/m^2/day	(Table 4 - 18)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	1.5	L/m^2/day	(Table 4 - 18)

- *R^{XX}_{YYYY} coefficient ratio, where the subindex YYYY and subindex XX represents the restaurant water consumption (Table 4 - 18), based on the parameters expressed in Table 4 - 40.*

Table 4 - 40 Ratio of restaurant water consumption based on the number of meals when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R^{NM}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the restaurant floor area to water consumption of the cooling and heating area based on the number of meals when its area is unknown.	5.26	meal/m^2
$R^{NM}_{IA,U}$	Ratio representing water consumption of the irrigation area based on the restaurant floor area to water consumption of the irrigation area based on the number of meals when its area is unknown.	5.3	meal/m^2

3. *Total Water Consumption (TWC) in restaurants based on the Number of Meals (NM) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{restaurant} = C_{NM,T} \cdot NM$$

Where:

- NM *is the number of meals in the restaurant; and can be calculated from the above equations based on available parameters.*
- $C_{NM,T}$ *is total unitary restaurant water consumption based on the number of meals. The analyzed references estimate it as 27 L/meal/day (Table 4 - 18).*

4.3.2.3.9 Daily restaurant water consumption equations based on the number of meals, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in restaurants based on the Number of Meals (NM) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{restaurant} = C_{NC} \cdot NM + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

- C_{XXX} *coefficients, where the subindex* C_{NC}*,* C_{CHA} *and* C_{IA} *represents the average unitary restaurant water consumption based on the parameters expressed in Table 4 - 41.*

Table 4 - 41 Unitary restaurant water consumption based on the number of meals, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{NM}	The average unitary restaurant water consumption based on the number of meals. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	25.1	L/meal/day	(Table 4 - 18)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *NM is the number of meals in the restaurant.*
- CHA *is the cooling and heating area in the restaurant.*
- IA *is the irrigation area in the restaurant.*

4.3.3 Cafe

The analysis of water consumption in cafes comprises five main micro-components: restroom consumption, irrigation, cooling and heating, kitchen and a final component which includes all other non-considered uses and any unintentional consumption. These water consumption micro-components are analyzed in section (3.4.3.1).

For the analysis to be meaningful and to obtain comparable figures between different studies and cafes, the average water consumption is analyzed in terms of a unit of a potential driver. More specifically, the drivers used to describe normalized water consumption in cafes are the floor area, the number of employees and the number of seats. Details of this analysis can be found in section (3.4.3.2). In any case, the large heterogeneity of water consumption in cafes should be highlighted, as seen from the high variability of results described by the different authors referenced in the present thesis.

More detailed relationships and conclusions can be raised with the data compiled and consolidated from several studies to improve the development of a water consumption model in cafes.

4.3.3.1 Water consumption micro-components in cafes

Table 4 - 42 shows the average weight of each water consumption micro-component from all the studies considered in this analysis. This table summarizes the findings and has helped develop simplified and easy to use equations that describe water consumption in cafes.

As a result, the sum of the different micro-components' average contribution does not necessarily have to add up exactly 100%. This is because the average contribution specified for a given micro-component (second row Table 4 - 42) is calculated from the various contributions of all previous studies. In the case of cafes, the sum of the contributions of the different uses sums up to 102%. Therefore, the average figures must be normalized so all micro-components' aggregated contribution is exactly 100%. The normalized values of these contributions are presented in row 3.

This table also shows the cafe's average daily water consumption based on the various drivers found in previous literature, as expressed in the floor area, the number of employees, and the number of seats.

The normalized figures obtained for each one of these drivers are the following:

- The average figure for the daily water consumption per floor area is 9.8 L/m^2/day, obtained and calculated through a frequency distribution analysis of the data extracted from the different studies (Figure 3 - 61).
- In the same manner, it has been obtained that the average value for the daily water consumption per employee is 282 L/employee/day (Figure 3 - 62).
- Finally, it has been derived that the average daily water consumption per seat is 79 L/seat/day (Figure 3 - 63).

Table 4 - 42 Contribution of water consumption micro-components in cafes. Average figures and benchmarks

Cafe water consumption micro-components and its unitary parameters.	Kitchen	Restrooms	Other	Landscape	Cooling and heating	Total
Percentage of water consumption micro-components.	50%	32%	13%	5%	2%	102%
Modified percentage of water consumption micro-components.	49%	31%	13%	5%	2%	100%
Average daily water consumption, based on the floor area (L/m²/day).	4.80	3.04	1.27	0.49	0.20	9.8
Average daily water consumption, based on the number of employees (L/employee/day).	138.18	87.42	36.66	14.1	5.64	282
The average daily water consumption is based on the number of seats (L/seat/day).	38.71	24.49	10.27	3.95	1.58	79

4.3.3.2 Model assumptions in describing water consumption in cafes

From Table 4 - 42, the following equations can be derived based on the assumption that cafe water consumption can be obtained as a function of the main drivers previously mentioned: floor area, number of employees and seats. The influence of these drivers and how their contribution may affect water consumption in a cafe must be reflected in the cafe water model to be applied.

Cafe water consumption consists of different micro-components, as discussed in detail in section (3.4.3.1). Considering the previously mentioned drivers, it seems reasonable to assume that the water consumption due to irrigation, cooling, and heating should only be related to their coverage area. Therefore, if the irrigation area (IA) and the cooling and heating area (CHA) are known, the water consumption of these components can be easily determined utilizing the average daily water consumption in the cooling and heating area (CHA) - 0.9 L/m²/day (Figure 3 - 33) - and the average daily water consumption in irrigation area (IA) - 3.5 L/m²/day (Figure 3 - 27). But, if the irrigation area (IA) and the cooling and heating area (CHA) are unknown, the water consumption of these uses needs to be estimated as a function ratio in terms of other drivers' expression functions.

4.3.3.3 Daily cafe water consumption equations

Daily cafe water consumption equations can be developed based on the floor area (FA), the number of employees (NE) and the number of customers (NC) when the cooling and heating area (CHA) and irrigation area (IA) are known and unknown or cannot be estimated.

4.3.3.3.1 Daily cafe water consumption equations based on the floor area

1. *Total Water Consumption (TWC) in the cafe based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{\text{cafe}} = C_{FA} \cdot FA + C_{CHA} \cdot (\text{CHA}) + C_{IA} \cdot (\text{IA})$$

Where:

– C_{XXX} *coefficients, where the subindex* C_{FA}, C_{CHA} *and* C_{IA} *represents the average unitary cafe water consumption based on the parameters expressed in Table 4 - 43.*

Table 4 - 43 Unitary cafe water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{FA}	The average unitary cafe water consumption based on the floor area. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	9.1	$L/m^2/day$	(Table 4 - 42)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	$L/m^2/day$	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	$L/m^2/day$	(Figure 3 - 27)

– *FA is the cafe's floor area, calculated from the equations based on the available parameters.*

$FA = NE \cdot R_{NE}^{FA}$

$FA = NC \cdot R_{NC}^{FA}$

– R_{YY}^{XX} *coefficient ratio, where the subindex YY and subindex XX represents the cafe water consumption (Table 4 - 42), based on the parameters expressed in Table 4 - 44.*

Table 4 - 44 Ratio of cafe water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{NE}^{FA}	Ratio representing the water consumption based on the number of employees to water consumption based on the cafe floor area. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	29	m^2/employee
R_{NC}^{FA}	Ratio representing the water consumption based on the number of customers to water consumption based on the cafe floor area. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	8.06	m^2/customer

2. *Total Water Consumption (TWC) in the cafe based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{\text{cafe}} = FA \cdot (C_{FA} + C_{CHA,U} + C_{IA,U})$$

Where:

– *C_{XXX} coefficients where the subindex C_{FA}, $C_{CHA,U}$ and $C_{IA,U}$ represents unitary cafe water consumption based on the parameters as expressed in Table 4 - 45*

Table 4 - 45 Unitary cafe water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.2	L/m^2/day	(Table 4 - 42)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	0.49	L/m^2/day	(Table 4 - 42)

3. *Total Water Consumption (TWC) in the cafe based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{\text{cafe}} = C_{FA,T} \cdot FA$$

Where:

– *FA is the floor area of the cafe and can be calculated from the equations above based on available parameters.*

– $C_{FA,T}$ *is total unitary cafe water consumption based on the restaurant floor area. From the analyzed references, it can be estimated as 9.8 L/m²/day (Table 4 - 42).*

4.3.3.3.2 Daily cafe water consumption equations based on the number of employees

1. *Total Water Consumption (TWC) in the cafe based on the number of employees (NE) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{cafe} = C_{NE} \cdot NE + C_{CHA} \cdot (NE/R^{NE}_{CHA}) + C_{IA} \cdot (NE/R^{NE}_{IA})$$

Where:

- C_{XXX} *coefficients, where the subindex* C_{NE}, C_{CHA} *and* C_{IA} *represents the average unitary cafe water consumption based on the parameters in Table 4 - 46.*

Table 4 - 46 Unitary cafe water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NE}	The average unitary cafe water consumption based on the number of employees. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	262	L/employee/day	(Table 4 - 42)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *NE is the number of employees in the cafe and can be calculated from the equations based on the parameters available.*

  NE = $FA \cdot R^{NE}_{FA}$

  NE = $NS \cdot R^{NE}_{NS}$

- R^{XX}_{YYY} *coefficient ratio, where the subindex YYY and subindex XX represents the cafe water consumption (Table 4 - 42), based on the parameters expressed in Table 4 - 47.*

Table 4 - 47 Ratio of cafe water consumption based on the number of employees when the cooling and heating areas (CHA) and irrigation areas (IA) are known

Coefficient Ratio	**Definition**	**Value**	**Unit**
R_{FA}^{NE}	Ratio representing water consumption based on the cafe floor area to water consumption based on the number of employees. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.03	employee/m^2
R_{NS}^{NE}	Ratio representing water consumption based on the number of employees to water consumption based on the number of customers. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.28	employee/seat
R_{CHA}^{NE}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the number of employees when its area is known.	0.16	employee/m^2
R_{IA}^{NE}	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the number of employees when its area is known.	0.24	employee/m^2

2. *Total Water Consumption (TWC) in the cafe based on the Number of Employees (NE) when Cooling and Heating area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{cafe} = NE \cdot (C_{NE} + C_{CHA,U} \cdot (1/R^{NE}_{CHA,U}) + C_{IA,U} \cdot (1/R^{NE}_{IA,U}))$$

Where:

– C_{XXX} *coefficients where the subindex* C_{NE}, $C_{CHA,U}$ *and* $C_{IA,U}$ *represents the average unitary cafe water consumption based on the parameters expressed in Table 4 - 48.*

Table 4 - 48 Unitary cafe water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.2	$L/m^2/day$	(Table 4 - 42)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	0.49	$L/m^2/day$	(Table 4 - 42)

– R^{XXX}_{YYY} *coefficient ratio, where the subindex YYY and subindex XXX represents the cafe water consumption (Table 4 - 42), based on the parameters expressed in Table 4 - 49.*

Table 4 - 49 Ratio of cafe water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R^{NE}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the cafe floor area to water consumption of the cooling and heating area based on the number of employees when its area is unknown.	0.035	$employee/m^2$
$R^{NE}_{IA,U}$	Ratio representing water consumption of the irrigation area based on the cafe floor area to water consumption of the irrigation area based on the number of employees when its area is unknown.	0.12	$employee/m^2$

3. *Total Water Consumption (TWC) in the cafe based on the Number of Employees (NE) when Cooling and Heating area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{cafe} = C_{NE,T} \cdot NE$$

Where:

- NE *is the number of employees in the cafe; and can be calculated from the above equations based on available parameters.*
- $C_{NE,T}$ *is total unitary cafe water consumption based on the number of employees. From the analyzed references, it can be estimated as 282 L/employee/day (Table 4 - 42).*

4.3.3.3.3 Daily cafe water consumption equations based on the number of employees, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the cafe based on the Number of Employees (NE), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{cafe} = C_{NE} \cdot NE + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

– *C_{XXX} coefficients, where the subindex C_{NE}, C_{CHA} and C_{IA} represents the average unitary cafe water consumption based on the parameters expressed in Table 4 - 50.*

Table 4 - 50 Unitary cafe water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NE}	The average unitary cafe water consumption based on the number of employees. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	262	L/employee/day	(Table 4 - 42)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	$L/m^2/day$	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	$L/m^2/day$	(Figure 3 - 27)

– *NE is the number of employees in the cafe.*

– *CHA is the cooling and heating area in the cafe.*

– *IA is the irrigation area in the cafe.*

4.3.3.3.4 Daily cafe water consumption equations based on the number of seats

1. *Total Water Consumption (TWC) in the cafe based on the Number of Seats (NS) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{cafe} = NS \cdot (C_{NS} + C_{CHA} \cdot (1/R_{CHA}^{NS}) + C_{IA} \cdot (1/R_{IA}^{NS}))$$

Where:

– C_{XXX} *coefficients, where the subindex* C_{NS}, C_{CHA} *and* C_{IA} *represents the average unitary cafe water consumption based on the parameters expressed in Table 4 - 51.*

Table 4 - 51 Unitary cafe water consumption based on the number of seats when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NS}	The average unitary cafe water consumption based on the number of seats. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	38.1	L/seat/day	(Table 4 - 42)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

– NS *is the number of seats in the cafe; and can be calculated from the equations based on available parameters.*

NS $= FA \cdot R_{FA}^{NS}$

NS $= NE \cdot R_{NE}^{NS}$

– R_{YYY}^{XX} *coefficient ratio, where the subindex YYY and subindex XX represents the cafe water consumption (Table 4 - 42), based on the parameters expressed in Table 4 - 52.*

Table 4 - 52 Ratio of cafe water consumption based on the number of seats when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{FA}^{NS}	Ratio representing water consumption based on the cafe floor area to water consumption based on the number of seats. This consumption ratio includes restrooms, kitchen, and others/unaccounted consumption.	0.73	seat/m^2
R_{NE}^{NS}	Ratio representing water consumption based on the number of employees to water consumption based on the number of seats. This consumption ratio includes restrooms, kitchen, and others/ unaccounted consumption.	11.83	seat/employee
R_{CHA}^{NS}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the number of seats when its area is known.	2.18	seat/m^2
R_{IA}^{NS}	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the number of seats when its area is known.	0.87	seat/m^2

2. *Total Water Consumption (TWC) in the cafe based on Number of Seats (NS) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{cafe} = NS \cdot C_{NS} + C_{CHA,U} \cdot (1/R^{NS}_{CHA,U}) + C_{IA,U} \cdot (1/R^{NS}_{IA,U})$$

Where:

- C_{XXX} *coefficients where the subindex* C_{NS}, $C_{CHA,U}$ *and* $C_{IA,U}$ *represents the unitary cafe water consumption based on the parameters expressed in Table 4 - 53.*

Table 4 - 53 Unitary cafe water consumption based on the number of customers when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.2	$L/m^2/day$	(Table 4 - 42)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	0.49	$L/m^2/day$	(Table 4 - 18)

- R^{XX}_{YYY} *coefficient ratio, where the subindex YYY and subindex XX represents the cafe water consumption (Table 4 - 42), based on the parameters expressed in Table 4 - 54.*

Table 4 - 54 Ratio of cafe water consumption based on the number of seats when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R^{NS}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the cafe floor area to water consumption of the cooling and heating area based on the number of seats when its area is unknown.	0.12	$seat/m^2$
$R^{NS}_{IA,U}$	Ratio representing water consumption of the irrigation area based on the cafe floor area to water consumption of the irrigation area based on the number of seats when its area is unknown.	0.87	$seat/m^2$

3. *Total Water Consumption (TWC) in the cafe based on Number of Seats (NS) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{cafe} = C_{NS,T} \cdot NS$$

Where:

- NS *is the number of seats in the café; and can be calculated from the above equations based on available parameters.*
- $C_{NS,T}$ *is total unitary cafe water consumption based on the number of seats. The analyzed references estimate it as 79 L/seat/day (Table 4 - 42).*

4.3.3.3.5 Daily cafe water consumption equations based on the number of seats, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the cafe based on Number of Seats (NS), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{cafe} = C_{NS} \cdot NS + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

– *C_{XXX} coefficients, where the subindex C_{NS}, C_{CHA} and C_{IA} represents the average unitary cafe water consumption based on the parameters expressed in Table 4 - 55.*

Table 4 - 55 Unitary cafe water consumption based on the number of seats when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NS}	The average unitary cafe water consumption based on the number of seats. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	38.1	L/seat/day	(Table 4 - 42)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

– *NS is the number of seats in the cafe.*

– *CHA is the cooling and heating area in the cafe.*

– *IA is the irrigation area in the cafe.*

4.3.4 Office

The analysis of water consumption in offices comprises five main micro-components, namely restroom consumption, irrigation, cooling and heating, kitchen and a final component which includes all other non-considered uses and any unintentional consumption. These water consumption micro-components are analyzed in section (3.4.4.1).

For the analysis to be meaningful and to obtain comparable figures between different studies and offices, the average water consumption is analyzed in terms of a unit of a potential driver. More specifically, the drivers used to describe normalized water consumption in offices are the floor area and the number of employees. Details of this analysis can be found in section (3.4.4.2). In any case, the large heterogeneity of water consumption in offices should be highlighted, as seen from the high variability of results described by the different authors referenced in the present thesis.

With the data compiled and consolidated from several studies, more detailed relationships and conclusions can be raised to improve the development of a water consumption model in offices.

4.3.4.1 Water consumption micro-components in office

Table 4 - 56 shows the average weight of each water consumption micro-component from all the studies considered in this analysis. This table summarizes the findings and has helped develop simplified and easy to use equations that describe water consumption in offices.

As a result, the sum of the different micro-components' average contribution does not necessarily have to add up exactly 100%. This is because the average contribution specified for a given micro-component (second row in Table 4 - 56) is calculated from the various contributions of all previous studies. In the offices' case, the different uses' contributions sum up to 97%. Therefore, the average figures must be normalized so all micro-components' aggregated contribution is exactly 100%. The normalized values of these contributions are presented in row 3.

This table also shows the office's average daily water consumption based on the various drivers found in previous literature, as expressed in terms of the floor area and the number of employees.

The normalized figures obtained for each one of these drivers are the following:

- The average daily water consumption per floor area is 2.9 L/m^2/day, obtained and calculated through a frequency distribution analysis of the data extracted from the different studies (Figure 3 - 66).
- In the same manner, it has been obtained that the average value for the daily water consumption per employee is 29.1 L/employee/day (Figure 3 - 69).

Table 4 - 56 Contribution of water consumption micro-components in offices. Average figures and benchmarks

Office water consumption micro-components.	Restroom	Cooling and heating	Landscaping	Kitchen	Other/ unaccounted	Total
Percentage of water consumption micro-components.	38%	28%	19%	6%	6%	97%
Modified percentage of water consumption micro-components.	39%	29%	20%	6%	6%	100%
Daily water consumption, based on the number of employees (L/employee/day)	11.4	8.4	5.8	1.7	1.7	29.1
Daily water consumption, based on floor area (L/m^2/day)	1.1	0.8	0.6	0.2	0.2	2.9

4.3.4.2 Model assumptions in describing water consumption in the office

From Table 4 - 56, the following equations can be derived based on the assumption that office water consumption can be obtained as a function of the main drivers previously mentioned: floor area of the office and number of employees. The influence of these drivers and how their contribution may affect water consumption in an office needs to be reflected in the office water model.

Office water consumption consists of different micro-components, as discussed in detail in section (3.4.4.1). Considering the previously mentioned drivers, it seems reasonable to assume that the water consumption due to irrigation, cooling, and heating should only be related to their coverage area. Therefore, if the irrigation area (IA) and the cooling and heating area (CHA) are known, the water consumption of these components can be easily determined utilizing the average daily water consumption in the cooling and heating area (CHA) - 0.9 L/m^2/day (Figure 3 - 33) - and the average daily water consumption in irrigation area (IA) - 3.5 L/m^2/day (Figure 3 - 27). But, if the irrigation area (IA) and the cooling and heating area (CHA) are unknown, the water consumption of these uses needs to be estimated as a function ratio in terms of other drivers' expression functions.

4.3.4.3 Daily office water consumption equations

Daily office water consumption equations can be developed based on the number of employees (NE) and the floor area (FA) of the office building when the cooling and heating area (CHA) and irrigation area (IA) are known and unknown.

4.3.4.3.1 Daily office water consumption equations based on the number of employees

1. *Total Water Consumption (TWC) in the office based on Number of Employees (NE) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{office} = NE \cdot C_{NE} + C_{CHA} \cdot (1/R_{CHA}^{NE}) + C_{IA} \cdot (1/R_{IA}^{NE}))$$

Where:

– C_{XXX} *coefficients, where the subindex* C_{NE}, C_{CHA} *and* C_{IA} *represents the average unitary office water consumption based on the parameters expressed in Table 4 - 57.*

Table 4 - 57 Unitary office water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NE}	The average unitary office water consumption based on the number of employees. This consumption includes restrooms, kitchen, and others /unaccounted consumption.	14.8	L/employee/day	(Table 4 - 56)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

– *NE is the number of employees in the office and can be calculated from the equations based on the parameters available.*

NE =FA$\cdot$ R_{FA}^{NE}

– R_{YYY}^{XX} *coefficient ratio, where the subindex YYY and subindex XX represents the office water consumption (Table 4 - 56) based on the parameters expressed in Table 4 - 58.*

Table 4 - 58 Ratio of office water consumption based on the number of employees when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient ratio	Definition	Value	Unit
R_{FA}^{NE}	Ratio representing the total water consumption based on office floor area to the total water consumption based on employees.	0.09	employee/m^2
R_{CHA}^{NE}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the number of employees when its area is known.	0.1	employee/m^2
R_{IA}^{NE}	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to water consumption of the irrigation area based on the number of employees when its area is known.	0.6	employee/m^2

2. *Total Water Consumption (TWC) in the office based on Number of Employees (NE) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{office} = NE \cdot (C_{NE} + C_{CHA,U} \cdot (1/R_{CHA,U}^{NE}) + C_{IA,U} \cdot (1/R_{IA,U}^{NE}))$$

Where:

- *C_{XXX} coefficients where the subindex C_{NE}, $C_{CHA,U}$ and $C_{IA,U}$ represents the average unitary office water consumption based on the parameters expressed in Table 4 - 59.*

Table 4 - 59 Unitary office water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
C_{NE}	The average unitary office water consumption based on the number of employees. This consumption includes restrooms, kitchen, and others /unaccounted consumption.	14.8	L/employee/day	(Table 4 - 56)
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when it is unknown based on floor area.	0.8	L/m^2/day	(Table 4 - 56)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when it is unknown based on floor area.	0.6	L/m^2/day	(Table 4 - 56)

– R_{YYYY}^{XX} *the coefficient ratios, where the subindex YYYY and subindex XX represents the office water consumption (Table 4 - 56) based on the parameters expressed in Table 4 - 60.*

Table 4 - 60 Ratio office water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient ratio	**Definition**	**Value**	**Unit**
$R_{CHA,U}^{NE}$	Ratio representing water consumption of the cooling and heating in floor area to water consumption of the cooling and heating based on the number of employees when its area is unknown.	0.9	employee / m^2
$R_{IA,U}^{NE}$	Ratio representing water consumption of the irrigation in floor area to water consumption of the irrigation based on the number of employees when its area is unknown.	.01	employee / m^2

3. *Total Water Consumption (TWC) in the office based on Number of Employees (NE) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{office} = C_{NE,T} \cdot NE$$

Where:

– *NE is the number of employees in the office and can be calculated from the above equations based on available parameters.*

– $C_{NE,T}$ *is total unitary office water consumption per employee. From the analyzed references, it can be estimated as 29.1 L/employee/day (Table 4 - 56).*

4.3.4.3.2 Daily office water consumption equations based on the number of employees, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the office is based on Number of Employees (NE), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{office} = C_{NE} \cdot NE + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

– C_{XXX} *coefficients, where the subindex* C_{NE}, C_{CHA} *and* C_{IA} *represents the average unitary office water consumption based on the parameters expressed in Table 4 - 61.*

Table 4 - 61 Unitary office water consumption based on the number of employees, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{NE}	The average unitary office water consumption based on the number of employees. This consumption includes restrooms, kitchen, and others /unaccounted consumption.	14.8	L/employee/day	(Table 4 - 56)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	$L/m^2/day$	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	$L/m^2/day$	(Figure 3 - 27)

– *NE is the number of employees in the office.*

– CHA *is the cooling and heating area in the office.*

– IA *is the irrigation area in the office.*

4.3.4.3.3 Daily office water consumption equations based on the floor area

1. *Total Water Consumption (TWC) in the office based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{office} = C_{FA} \cdot FA + C_{CHA} \cdot CHA + C_{IA} \cdot IA$$

Where:

- C_{XXX} *coefficients, where the subindex* C_{FA}, C_{CHA} *and* C_{IA} *represents the average unitary cafe water consumption based on the parameters expressed in Table 4 - 62.*

Table 4 - 62 Unitary office water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{FA}	The average unitary office water consumption based on the floor area. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	1.5	L/m^2/day	(Table 4 - 56)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *FA is the floor area in the office building and can be calculated from the equations based on available parameters.*

  FA =NA/ R_{FA}^{NE}

2. *Total Water Consumption (TWC) in the office is based on Floor Area (FA) when Cooling and Heating area (CHA) and Irrigation area (IA) are unknown*

$$TWC_{office} = FA \cdot (C_{FA} + C_{CHA,U} + C_{IA,U})$$

Where:

- C_{XXX} *coefficients where the subindex* C_{FA}, $C_{CHA,U}$ *and* $C_{IA,U}$ *represents the unitary cafe water consumption based on the parameters as expressed in Table 4 - 63.*

Table 4 - 63 Unitary office water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
C_{FA}	The average unitary office water consumption based on the floor area. This consumption includes restrooms, kitchen, and others/unaccounted consumption.	1.5	L/m^2/day	(Table 4 - 56)
$C_{CHA,U}$	The average unitary water consumption in cooling and heating area when its area is unknown.	0.8	L/m^2/day	(Table 4 - 56)
$C_{IA,U}$	The average unitary water consumption in an irrigation area when its area is unknown.	0.6	L/m^2/day	(Table 4 - 56)

3. *Total Water Consumption (TWC) in the office based on Floor Area (FA) when Cooling and Heating area (CHA) and Irrigation area (IA) are unknown, and they cannot be estimated*

$$TWC_{office} = C_{FA,T} \cdot FA$$

Where:

- *FA is the floor area in the office building and can be calculated from the above equations based on available parameters.*
- $C_{FA,T}$ *is total unitary office water consumption per floor area. From the analyzed references, it can be estimated as 2.9 L/m²/day (Table 4 - 56).*

4.3.5 Wholesale and retail

The analysis of water consumption in wholesale and retail comprises four main micro-components: restroom consumption, irrigation, cooling and heating and kitchen. These water consumption micro-components are analyzed in section (3.4.5.1).

For the analysis to be meaningful and to obtain comparable figures between different studies, wholesale and retail, the average water consumption is analyzed in terms of a unit of a potential driver. More specifically, the drivers used to describe normalized water consumption in wholesale and retails are the floor area and the number of employees. Details of this analysis can be found in section (3.4.5.2). In any case, the large heterogeneity of water consumption in wholesale and retails should be highlighted, as seen from the high variability of results described by the different authors referenced in the present thesis.

With the data compiled and consolidated from several studies, more detailed relationships and conclusions can be raised to improve the development of a water consumption model in wholesale and retails.

4.3.5.1 Water consumption micro-components in wholesale and retail

Table 4 - 64 shows the average weight of each water consumption micro-component from all the studies considered in this analysis. This table summarizes the findings and has helped develop simplified and easy to use equations that describe water consumption in wholesale and retail.

As a result, the sum of the different micro-components' average contribution does not necessarily have to add up exactly 100%. This is because the average contribution specified for a given micro-component (second row in Table 4 - 64) is calculated from the various contributions of all previous studies. In wholesale and retail, the sum of the different uses' contributions is up to 97%. Therefore, the average figures must be normalized so all micro-components' aggregated contribution is exactly 100%. The normalized values of these contributions are presented in row 3.

This table also shows the average daily water consumption in wholesale and retail based on the various drivers found in previous literature, expressed in terms of the floor area and the number of employees.

The normalized figures obtained for each one of these drivers are the following:

- The average daily water consumption per floor area is 2.1 L/m^2/day, obtained and calculated through a frequency distribution analysis of the data extracted from the different studies (Figure 3 - 73).
- In the same manner, it has been obtained that the average value for the daily water consumption per employee is 120 L/employee/day (Figure 3 - 76).

Table 4 - 64 Contribution of water consumption micro-components in wholesale and retails—average figures and benchmarks

Wholesale and retail trade water consumption micro-components and its unitary parameters.	Restroom	Kitchen	Landscaping	Cooling and heating	Total
Average percentage of water consumption micro-components.	26%	15%	38%	21%	100%
Average daily water consumption, based on the floor area (L/m²/day).	0.6	0.3	0.8	0.4	2.1
Average daily water consumption, based on the number of employees (L/employee/day).	31.2	18	45.6	25.2	120

4.3.5.2 Model assumptions in describing water consumption in wholesale and retail

From Table 4 - 64, the following equations can be derived based on the assumption that wholesale and retail water consumption can be obtained as a function of the main drivers previously mentioned: the wholesale and retail floor area and the number of employees. The influence of these drivers and how their contribution may affect water consumption in wholesale and retail needs to be reflected in the application of the water model.

Wholesale and retail water consumption consists of different micro-components, as discussed in section (3.4.5.1). Considering the previously mentioned drivers, it seems reasonable to assume that water consumption due to irrigation, cooling, and heating should only be related to their coverage area. Therefore, if the irrigation area (IA) and cooling and heating area (CHA) are known, the water consumption of these components can be easily determined through the average daily water consumption in cooling and heating area (CHA) - 0.9 $L/m^2/day$ (Figure 3 - 33) - and the average daily water consumption in irrigation area (IA) - 3.5 $L/m^2/day$ (Figure 3 - 27). But, if the irrigation area (IA) and cooling and heating area (CHA) are unknown, water consumption from these uses must be estimated as a function of other drivers.

4.3.5.3 Daily wholesale and retail trade water consumption equations

Daily wholesale and retail trade water consumption equations can be developed based on the number of employees (NE) or the floor area (FA) of the Wholesale and retail trade when the cooling and heating area (CHA) and irrigation area (IA) are known and unknown.

4.3.5.3.1 Daily wholesale and retail trade water consumption equations based on the floor area

1. *Total Water Consumption (TWC) in the wholesale and retail trade based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{wholesale\ and\ retail\ trade} = C_{FA}{\cdot}FA + C_{CHA}{\cdot}CHA + C_{IA}{\cdot}IA$$

Where:

– *C_{XXX} coefficients, where the subindex C_{FA}, C_{CHA} and C_{IA} represents the average unitary wholesale and retail trade water consumption based on the parameters expressed in Table 4 - 65.*

Table 4 - 65 Unitary wholesale and retail trade water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{FA}	The average unitary wholesale and retail trade water consumption based on the floor area. This consumption includes restrooms and kitchen.	0.9	L/m²/day	(Table 4 - 64)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m²/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m²/day	(Figure 3 - 27)

– *FA is the floor area in the wholesale and retail trade, which can be calculated from the equations based on available parameters.*

FA =NA/ R_{FA}^{NE}

– *CHA is the cooling and heating area in the wholesale and retail trade.*

– *IA is the irrigation area in the wholesale and retail trade.*

– *R_{YY}^{XX} coefficient ratio, where the subindex YY and subindex XX represents the wholesale and retail trade water consumption (Table 4 - 64) based on the parameters expressed in Table 4 - 66.*

Table 4 - 66 Ratio of wholesale and retail trade water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient ratio	Definition	Value	Unit
R_{FA}^{NE}	Ratio representing the total water consumption based on wholesale based on floor area to total water consumption based on the number of employees.	0.018	employee/m^2

2. *Total Water Consumption (TWC) in the wholesale and retail trade based on Floor Area (FA) when the Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{wholesale\ and\ retail\ trade} = FA \cdot (C_{FA} + C_{CHA,U} + C_{IA,U})$$

Where:

- *C_{XXX} coefficients where the subindex C_{FA}, $C_{CHA,U}$ and $C_{IA,U}$ represents unitary cafe water consumption based on the parameters as expressed in Table 4 - 67.*

Table 4 - 67 Unitary wholesale and retail trade water consumption based on floor area, when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.4	L/m^2/day	(Table 4 - 64)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	0.8	L/m^2/day	(Table 4 - 64)

3. *Total Water Consumption (TWC) in the wholesale and retail trade based on Floor Area (FA) when the Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{wholesale\ and\ retail\ trade} = C_{FA,T} \cdot FA$$

Where:

- *FA is the floor area in the wholesale and retail trade and can be calculated from the above equations based on available parameters.*
- *$C_{FA,T}$ is total unitary wholesale and retail trade water consumption per floor area. From the analyzed references, it can be estimated as 2.1 L/m²/day (Table 4 - 64).*

4.3.5.3.2 Daily wholesale and retail trade water consumption equations based on the number of employees

1. *Total Water Consumption (TWC) in the wholesale and retail trade based on Number of Employees (NE) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{wholesale\ and\ retail\ trade} = NE \cdot (\,C_{NE} + C_{CHA} \cdot (1/R_{CHA}^{NE}) \;+\; C_{IA} \cdot (1/R_{IA}^{NE}))$$

Where:

- C_{XXX} *coefficients, where the subindex* C_{NE}*,* C_{CHA} *and* C_{IA} *represents the average unitary wholesale and retail trade water consumption based on the parameters expressed in Table 4 - 68.*

Table 4 - 68 Unitary wholesale and retail trade water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NE}	The average unitary wholesale and retail trade water consumption based on the number of employees. This consumption includes restrooms and kitchen.	49.2	L/employee/day	(Table 4 - 68)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *NE is the number of wholesale and retail trade employees and can be calculated from equations based on available parameters.*

  NE =FA$\cdot$ R_{FA}^{NE}

- R_{YYY}^{XXX} *coefficient ratio, where the subindex YYY and subindex XXX represents the wholesale and retail trade water consumption (Table 4 - 64) based on the parameters expressed in Table 4 - 69.*

Table 4 - 69 Ratio of wholesale and retail trade water consumption based on the number of employees when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient ratio	Definition	Value	Unit
R_{FA}^{NE}	Ratio representing the total water consumption based on the wholesale and retail trade floor area to total water consumption based on the number of employees.	0.018	employee/m^2
R_{CHA}^{NE}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the	0.04	employee/m^2

	water consumption of the cooling and heating area based on the number of employees when its area is known.		
R_{IA}^{NE}	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the number of employees when its area is known.	0.07	employee/m^2

2. *Total Water Consumption (TWC) in the wholesale and retail trade based on Number of Employees (NE) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{wholesale\ and\ retail\ trad} = NE \cdot (C_{NE} + C_{CHA,U} \cdot (1/R_{CHA,U}^{NE}) + C_{IA,U} \cdot (1/R_{IA,U}^{NE}))$$

Where:

- *C_{XXX} coefficients where the subindex C_{NE}, $C_{CHA,U}$ and $C_{IA,U}$ represents the average unitary wholesale and retail trade water consumption (Table 4 - 64) based on the parameters expressed in Table 4 - 70.*

Table 4 - 70 Unitary wholesale and retail trade water consumption based on the number of employees when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	**Definition**	**Value**	**Unit**
C_{NE}	The average unitary office water consumption based on the number of employees. This consumption includes restrooms and kitchen.	49.2	L/employee/day
$C_{CHA,U}$	The average unitary water consumption in cooling and heating area when its area is unknown.	0.4	L/m^2/day
$C_{IA,U}$	The average unitary water consumption in an irrigation area when its area is unknown.	0.8	L/m^2/day

- *R_{YYYY}^{XX} the coefficient ratios, where the subindex YYYY and subindex XX represents the wholesale and retail trade water consumption (Table 4 - 64) based on the parameters expressed in Table 4 - 71.*

Table 4 - 71 Ratio wholesale and retail trade water consumption based on the number of employees when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient ratio	**Definition**	**Value**	**Unit**
$R_{CHA,U}^{NE}$	Ratio representing water consumption of the cooling and heating in floor area to water consumption of the cooling and heating per employee when its area is unknown.	63	employee/m^2
$R_{IA,U}^{NE}$	Ratio representing water consumption of the irrigation in floor area to water consumption of the irrigation per employee when its area is unknown.	57	employee/m^2

3. *Total Water Consumption (TWC) in the wholesale and retail trade based on Number of Employees (NE) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{wholesale\ and\ retail\ trad} = C_{NE,T} \cdot NE$$

Where:

- *NE is the number of wholesale and retail trade employees and can be calculated from the above equations based on available parameters.*
- $C_{NE,T}$ *is total unitary wholesale and retail trade water consumption per employee. The analyzed references estimate it as 120 L/employee/day (Table 4 - 64).*

4.3.5.3.3 Daily wholesale and retail trade water consumption equations based on the number of employees, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the wholesale and retail trade based on Number of Employees (NE) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{wholesale\ and\ retail\ trade} = C_{NE} \cdot NE + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

- *C_{XXX} coefficients, where the subindex C_{FA}, C_{CHA} and C_{IA} represents the average unitary wholesale and retail trade water consumption based on the parameters expressed in Table 4 - 72.*

Table 4 - 72 Unitary wholesale and retail trade water consumption based on the number of employees, cooling and heating area (CHA), and irrigation

Coefficient Name	Definition	Value	Unit	Reference
C_{NE}	The average unitary wholesale and retail trade water consumption based on the number of employees. This consumption includes restrooms and kitchen.	49.2	L/employee/day	(Table 4 - 68)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	$L/m^2/day$	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	$L/m^2/day$	(Figure 3 - 27)

- *NE is the number of employees in the wholesale and retail trade.*
- *CHA is the cooling and heating area in the wholesale and retail trade.*
- *IA is the irrigation area in the wholesale and retail trade.*

4.3.6 Schools

The analysis of school water consumption comprises six main micro-components: restroom consumption, irrigation, cooling and heating, kitchen, swimming pool and laundry. These water consumption micro-components are analyzed in section (3.4.6.1).

For the analysis to be meaningful and to obtain comparable figures between different studies and schools, the average water consumption is analyzed in terms of a unit of a potential driver. More specifically, the drivers used to describe normalized water consumption in schools are the floor area and the number of students. Details of this analysis can be found in section (3.4.6.2). In any case, the large heterogeneity of water consumption in elementary, secondary, high schools and schools, in general, should be highlighted, as seen from the high variability of results described by the different authors referenced in the present thesis.

With the data compiled and consolidated from several studies, more detailed relationships and conclusions can be raised to improve the development of a school water consumption model.

4.3.6.1 Water consumption micro-components in schools

Table 4 - 73 shows the average weight of each water consumption micro-component from all the studies considered in this analysis. This table summarizes the findings and has helped develop simplified and easy to use equations that describe water consumption in elementary, secondary, high school, and schools in general.

As a result, the sum of the different micro-components' average contribution does not necessarily have to add up exactly 100%. This is because the average contribution specified for a given micro-component (second row in Table 4 - 73) is calculated from the various contributions of all previous studies. In the schools' case, the sum of the contributions of the different uses sums up to 103%. Therefore, the average figures must be normalized so all micro-components' aggregated contribution is exactly 100%. The normalized values of these contributions are presented in a row.

This table also shows the average daily water consumption in elementary, secondary, high school, and schools in general based on the various drivers found in previous literature, as expressed in the floor area and the number of students.

The normalized figures obtained for each one of these drivers are the following:

- The average figure for the daily water consumption per square meter in elementary, secondary, high school and schools, in general, is 1.9, 2.1, 2.05, and 2.5 L/m^2/day, respectively, which have been obtained and calculated through a frequency distribution analysis of the data extracted from the different studies considered (Figure 3 - 79).
- In the same manner, it has been obtained that the average value for the daily water consumption per student is 26, 24, 32, and 30 L/ student/day (Figure 3 - 79).

Table 4 - 73 Contribution of water consumption micro-components in schools. Average figures and benchmarks

Schools water consumption micro-components and its unitary parameters.	Restroom	Cooling and heating	Landscaping	Kitchen	Laundry	Swimming Pool	Total
Average percentage of water consumption micro-components.	45%	16%	28%	10%	3%	1%	103%
Schools water consumption micro-components.	44%	16%	27%	10%	3%	1%	100%
Average daily water consumption in elementary school, based on the floor area ($L/m^2/day$).	0.83	0.30	0.52	0.18	0.06	0.02	1.9
Average daily water consumption in secondary school, based on the floor area ($L/m^2/day$).	0.92	0.33	0.57	0.20	0.06	0.02	2.1
Average daily water consumption in high school, based on the floor area ($L/m^2/day$).	0.90	0.32	0.56	0.20	0.06	0.02	2.05
Average daily water consumption in school, based on the floor area ($L/m^2/day$).	1.09	0.39	0.68	0.24	0.07	0.02	2.5
Average daily water consumption in elementary school, based on the number of students (L/student/day).	11.36	4.04	7.07	2.52	0.76	0.25	26
Average daily water consumption in secondary school, based on the number of students (L/student/day).	10.49	3.73	6.52	2.33	0.70	0.23	24
Average daily water consumption in high school, based on the number of students (L/student/day).	13.98	4.97	8.70	3.11	0.93	0.31	32
Average daily water consumption in Schools, based on the number of students (L/student/day).	8.74	3.11	5.44	1.94	0.58	0.19	20

4.3.6.2 Model assumptions in describing water consumption in schools

From Table 4 - 73, the following equations can be derived based on the assumption that elementary, secondary, high school and schools in general water consumption can be obtained as a function of the main drivers previously mentioned: floor area of the schools and the number of students. The influence of these drivers and how their contribution may affect water consumption in schools needs to be reflected in the schools' water model to be applied.

Schools water consumption consists of different micro-components, as discussed in detail in section (3.4.6.1). Considering the previously mentioned drivers, it seems reasonable to assume that the water consumption due to irrigation, cooling, and heating should only be related to their coverage area. Therefore, if the irrigation area (IA) and the cooling and heating area (CHA) are known, the water consumption of these components can be easily determined utilizing the average daily water consumption in the cooling and heating area (CHA) - 0.9 L/m²/day (Figure 3 - 33) - and the average daily water consumption in irrigation area (IA) - 3.5 L/m²/day (Figure 3 - 27). But, if the irrigation area (IA) and the cooling and heating area (CHA) are unknown, the water consumption of these uses needs to be estimated as a function ratio in terms of other drivers' expression functions.

4.3.6.3 Daily schools' water consumption equations

Daily elementary, secondary, high school and schools in general water consumption equations can be developed based on the floor area (FA) and the number of students (NS) when the cooling and heating area (CHA) and irrigation area (IA) are known and unknown.

4.3.6.3.1 Daily schools water consumption equations based on the floor area.

1. *Total Water Consumption (TWC) in the elementary, secondary, high school and schools in general based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{schools} = C_{FA}\cdot FA + C_{CHA}\cdot CHA + C_{IA}\cdot IA$$

Where:

- C_{XXX} *coefficients, where the subindex* C_{FA}, C_{CHA} *and* C_{IA} *represents the average unitary elementary, secondary, high school and schools, in general, water consumption based on the parameters expressed in Table 4 - 74Table 4 - 102.*

Table 4 - 74 Unitary schools water consumption based on floor area, when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
$C_{FA-elementry}$	The average unitary elementary school water consumption based on the floor area. This consumption includes restrooms, kitchen, laundry, and pools.	1.09	L/m²/day	(Table 4 - 73)

$C_{FA-\text{secondary}}$	The average unitary secondary school water consumption based on the floor area. This consumption includes restrooms, kitchen, laundry, and pool.	1.2	L/m^2/day	(Table 4 - 73)
$C_{FA-\text{high}}$	The average unitary high school water consumption based on the floor area. This consumption includes restrooms, kitchen, laundry, and pool.	1.17	L/m^2/day	(Table 4 - 73)
$C_{FA-\text{general}}$	The average unitary school as general school water consumption based on the floor area. This consumption includes restrooms, kitchen, laundry, and pool.	1.43	L/m^2/day	(Table 4 - 73)
C_{CHA}	The average unitary water consumption in cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

– *FA is the floor area in elementary, secondary, high school or schools in general and can be calculated from the equations based on available parameters.*

$$FA_{elementry} = NS \cdot R_{NS-elementry}^{FA-elementry}$$
$$FA_{secondary} = NS \cdot R_{NS-secondary}^{FA-secondary}$$
$$FA_{high} = NS \cdot R_{NS-high}^{FA-high}$$
$$FA_{general} = NS \cdot R_{NS-general}^{FA-general}$$

– R_{YYY}^{XXX} *coefficient ratio, where the subindex YYY and subindex XXX represent the elementary, secondary, high school and schools as general water consumption (Table 4 - 73Table 4 - 96), based on the parameters expressed in Table 4 - 75Table 4 – 89.*

Table 4 - 75 Ratio of schools water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
$R_{NS-elementry}^{FA-elementry}$	Ratio representing the water consumption based on the number of students to water consumption based on the elementary school floor area. This consumption includes restrooms, kitchen, laundry, and swimming pool.	13.7	m^2/student
$R_{NS-secondary}^{FA-secondary}$	Ratio representing the water consumption based on the number of students to water consumption based on the secondary school floor area. This consumption includes restrooms, kitchen, laundry, and swimming pool.	11.4	m^2/student
$R_{NS-high}^{FA-high}$	Ratio representing the water consumption based on the number of students to water consumption based on the high school floor area. This	15.6	m^2/student

	consumption includes restrooms, kitchen, laundry, and swimming pool.		
$R_{NS-general}^{FA-general}$	Ratio representing the water consumption based on the number of students to water consumption based on schools as general floor area. This consumption includes restrooms, kitchen, laundry, and swimming pool.	8	m^2/student

2. *Total Water Consumption (TWC) in elementary, secondary, high school and schools in general based on Floor Area (FA) per square meter when the Cooling and Heating area (CHA) and Irrigation area (IA) are unknown*

$$TWC_{schools} = C_{FA} \cdot FA + C_{CHA,U} \cdot CHA + C_{IA,U} \cdot IA$$

Where:

- C_{XXX} *coefficients where the subindex* C_{FA}, $C_{CHA,U}$ *and* $C_{IA,U}$ *represents the average unitary elementary, secondary, high school and schools, in general, water consumption based on the parameters as expressed in Table 4 - 76.*

Table 4 - 76 Unitary schools' water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U-elementry}$	The average unitary water consumption in the elementary school cooling and heating area when its area is unknown.	0.3	L/m^2/day	(Table 4 - 73)
$C_{CHA,U-secondary}$	The average unitary water consumption in the secondary school cooling and heating area when its area is unknown.	0.33	L/m^2/day	(Table 4 - 73)
$C_{CHA,U-high}$	The average unitary water consumption in the high school cooling and heating area when its area is unknown.	0.32	L/m^2/day	(Table 4 - 73)
$C_{CHA,U-general}$	The average unitary water consumption in the school as general cooling and heating area when its area is unknown.	0.39	L/m^2/day	(Table 4 - 73)
$C_{IAU-elementry}$	The average unitary water consumption in the elementary school irrigation area when its area is unknown.	0.52	L/m^2/day	(Table 4 - 73)
$C_{IA,U-secondary}$	The average unitary water consumption in the secondary school irrigation area when its area is unknown.	0.57	L/m^2/day	(Table 4 - 73)
$C_{IA,U-high}$	The average unitary water consumption in the high school irrigation area when its area is unknown.	0.56	L/m^2/day	(Table 4 - 73)
$C_{IA,U-general}$	The average unitary water consumption in the schools in general irrigation area when its area is unknown.	0.68	L/m^2/day	(Table 4 - 73)

3. *Total Water Consumption (TWC) in elementary, secondary, high school and schools, in general, based on Floor Area (FA) when the Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{schools} = C_{FA,T} \cdot FA$$

Where:

- FA *the floor area in the schools, and can be calculated from the above equations based on available parameters.*
- $C_{FA,T}$ *is total unitary school water consumption based on the elementary, secondary, high school and schools, in general, floor area. From the analyzed references, it can be estimated as 1.9, 2.1, 2.05 and 2.5 L/m²/day, respectively (Table 4 - 73).*

4.3.6.3.2 Daily schools water consumption equations based on the number of students

1. *Total Water Consumption (TWC) in the elementary, secondary, high school and schools in general based on Number of Students (NS) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{schools} = NS \cdot (C_{NS} + C_{CHA} \cdot (1/R_{CHA}^{NS}) + C_{IA} \cdot (1/R_{IA}^{NS}))$$

Where:

- *C_{XXX} coefficients, where the subindex C_{NS}, C_{CHA} and C_{IA} represents the average unitary elementary, secondary, high school and schools, in general, water consumption based on the parameters expressed in Table 4 - 77.*

Table 4 - 77 Unitary schools' water consumption based on the number of students when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
$C_{NS-elementry}$	The average unitary elementary school water consumption based on the number of students. This consumption includes restrooms, kitchen, laundry, and pool.	14.89	L/student/day	(Table 4 - 73)
$C_{NS-secondary}$	The average unitary secondary school water consumption based on the number of students. This consumption includes restrooms, kitchen, laundry, and pool.	13.75	L/student/day	(Table 4 - 73)
$C_{NS-high}$	The average unitary high school water consumption based on the number of students. This consumption includes restrooms, kitchen, laundry, and pool.	18.33	L/student/day	(Table 4 - 73)
$C_{NS-general}$	The average unitary school as general water consumption based on the number of students. This consumption includes restrooms, kitchen, laundry, and pool.	11.46	L/student/day	(Table 4 - 73)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *NS is the number of students in elementary, secondary, high school and schools, in general, and can be calculated from equations based on the available parameters.*

  $NS = FA \cdot R_{FA}^{NS}$

- *R_{YYY}^{XXX} coefficient ratio, where the subindex YYY and subindex XXX represents the elementary, secondary, high school and schools in general water consumption (Table 4 - 73), based on the parameters expressed in Table 4 - 78.*

Table 4 - 78 Ratio of schools water consumption based on the number of students when the cooling and heating areas (CHA) and irrigation areas (IA) are known

Coefficient Ratio	Definition	Value	Unit
$\mathrm{R}_{\mathrm{FA-elementary}}^{\mathrm{NS-elementary}}$	Ratio representing water consumption based on the elementary school floor area to water consumption based on the number of students. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and pool.	0.07	student/m^2
$\mathrm{R}_{\mathrm{FA-secondary}}^{\mathrm{NS-secondary}}$	Ratio representing water consumption based on the secondary school floor area to water consumption based on the number of students. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and pool.	0.09	student/m^2
$\mathrm{R}_{\mathrm{FA-high}}^{\mathrm{NS-high}}$	Ratio representing water consumption based on the high school floor area to water consumption based on the number of students. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and pool.	0.06	student/m^2
$\mathrm{R}_{\mathrm{FA-general}}^{\mathrm{NS-general}}$	Ratio representing the water consumption based on the schools as general floor area to water consumption based on the number of students. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and pool.	0.13	student/m^2
$\mathrm{R}_{\mathrm{CHA}}^{\mathrm{NS-elementary}}$	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area in elementary school based on the number of students when its area is known.	0.22	student/m^2
$\mathrm{R}_{\mathrm{CHA}}^{\mathrm{NS-secondary}}$	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area in a secondary school based on the number of students when its area is known.	0.24	student / m^2

$R_{CHA}^{NS-high}$	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area in high school based on the number of students when its area is known.	0.18	$student/m^2$
$R_{CHA}^{NS-general}$	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area in schools in general based on the number of students when its area is known.	0.29	$student/m^2$
$R_{IA}^{NS-elementary}$	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area in elementary school based on the number of students when its area is known.	0.49	$student/m^2$
$R_{IA}^{NS-secondary}$	Ratio representing water consumption of irrigation area (Figure 3 - 27) to water consumption of irrigation area in a secondary school based on the number of students, when its area is known	0.53	$student/m^2$
$R_{IA}^{NS-high}$	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area in high school based on the number of students when its area is known	0.40	$student/m^2$
$R_{IA}^{NS-general}$	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area in school, in general, based on the number of students when its area is known	0.64	$student/m^2$

2. *Total Water Consumption (TWC) in the elementary, secondary, high school and schools in general based on Number of Students (NS) when Cooling and Heating area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{schools} = NS \cdot (C_{NS} + C_{CHA,U} \cdot (1/R^{NS}_{CHA,U}) + C_{IA,U} \cdot (1/R^{NS}_{IA,U}))$$

Where:

– *C_{XXX} coefficients where the subindex C_{NS}, $C_{CHA,U}$ and $C_{IA,U}$ represents the average unitary elementary, secondary, high school and schools, in general, water consumption based on the parameters expressed in Table 4 - 79.*

Table 4 - 79 Unitary schools water consumption based on the number of students, when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	**Definition**	**Value**	**Unit**	**Reference**
$C_{CHA,U-elementary}$	The average unitary elementary school water consumption in the cooling and heating area when its area is unknown.	4.04	L/m^2/day	(Table 4 - 73)
$C_{CHA,U-secondary}$	The average unitary secondary school water consumption in the cooling and heating area when its area is unknown.	3.73	L/m^2/day	(Table 4 - 73)
$C_{CHA,U-high}$	The average unitary high school water consumption in the cooling and heating area when its area is unknown.	4.97	L/m^2/day	(Table 4 - 73)
$C_{CHA,U-general}$	The average unitary general school water consumption in the cooling and heating area when its area is unknown.	3.11	L/m^2/day	(Table 4 - 73)
$C_{IA,U-elementary}$	The average unitary elementary school water consumption in the irrigation area when its area is unknown.	7.07	L/m^2/day	(Table 4 - 73)
$C_{IA,U-secondary}$	The average unitary secondary school water consumption in the irrigation area when its area is unknown.	6.52	L/m^2/day	(Table 4 - 73)
$C_{IA,U-high}$	The average unitary high school water consumption in the irrigation area when its area is unknown.	8.70	L/m^2/day	(Table 4 - 73)
$C_{IA,U-general}$	The average unitary general school water consumption in the irrigation area when its area is unknown.	5.44	L/m^2/day	(Table 4 - 73)

– *R^{XXX}_{YYYYY} coefficient ratio, where the subindex YYYYY and subindex XXX represents the elementary, secondary, high school and schools in general* *water consumption (Table 4 - 73), based on the parameters expressed in Table 4 - 80.*

Table 4 - 80 Ratio of schools' water consumption based on the number of students when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R_{CHA,U-elementary}^{NS-elementary}$	Ratio representing water consumption of the cooling and heating area based on the elementary school floor area to the elementary school water consumption of the cooling and heating area based on the number of students when its area is unknown.	0.07	student/m^2
$R_{CHA,U-secondary}^{NS-secondary}$	Ratio representing water consumption of the cooling and heating area based on s the secondary school floor area to the secondary school water consumption of the cooling and heating area based on the number of students when its area is unknown	0.08	student/m^2
$R_{CHA,U-high}^{NS-high}$	Ratio representing water consumption of the cooling and heating area based on the high school floor area to the high school water consumption of the cooling and heating area based on the number of students when its area is unknown	0.06	student/m^2
$R_{CHA,U-\ general}^{NS-\ general}$	Ratio representing water consumption of the cooling and heating area based on the schools as general floor area to the water consumption of the cooling and heating area in the school as general based on the number of students when its area is unknown	0.13	student/m^2
$R_{IA,U-elementary}^{NS-elementary}$	Ratio representing water consumption of the irrigation area based on the elementary school floor area to the elementary school water consumption of the irrigation area based on the number of students when its area is unknown.	0.1	student/m^2
$R_{IA,U-secondary}^{NS-secondary}$	Ratio representing water consumption of the irrigation area based on the secondary school floor area to the secondary school water consumption of the irrigation area based on the number of students when its area is unknown.	0.09	student/m^2
$R_{IA,U-high}^{NS-high}$	Ratio representing water consumption of the irrigation area based on the high school floor area to the high school water consumption of the irrigation area based on the number of students when its area is unknown.	0.1	student/m^2

$R_{IA,U-general}^{NS-general}$	Ratio representing water consumption of the irrigation area based on the school as general floor area to water consumption of the irrigation area in school as general based on the number of students when its area is unknown.	0.13	student/m^2

3. *Total Water Consumption (TWC) in elementary, secondary, high school and schools, in general, based on Number of Students (NS) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{schools} = C_{NS,T} \cdot NS$$

Where:

- NS *is the number of students in the schools; and can be calculated from the above equations based on the available parameters.*
- $C_{NS,T}$ *The total unitary elementary, secondary, high school and schools, in general, water consumption is based on the number of students. From the analyzed references, it can be estimated as 26, 24, 32 and 20 L/student/day, respectively (Table 4 - 73Table 4 - 96).*

4.3.6.3.3 Daily schools water consumption equations based on the number of students, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the elementary, secondary, high school and schools in general based on Number of Students (NS), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{schools} = C_{NS} \cdot NS + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where: -

- *C_{XXX} coefficients, where the subindex C_{NS}, C_{CHA} and C_{IA} represents the average unitary elementary, secondary, high school and schools, in general, water consumption based on the parameters expressed in Table 4 - 81.*

Table 4 - 81 Unitary schools' water consumption based on the number of students, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
$C_{NS-elementary}$	The average unitary elementary school water consumption based on the number of students. This consumption includes restrooms, kitchen, laundry, and pool.	14.89	L/student/day	(Table 4 - 73)
$C_{NS-secondary}$	The average unitary secondary school water consumption based on the number of students. This consumption includes restrooms, kitchen, laundry, and pool.	13.75	L/student/day	(Table 4 - 73)
$C_{NS-high}$	The average unitary high school water consumption based on the number of students. This consumption includes restrooms, kitchen, laundry, and pool.	18.33	L/student/day	(Table 4 - 73)
$C_{NS-general}$	The average unitary school as general water consumption based on the number of students. This consumption includes restrooms, kitchen, laundry, and pool.	11.46	L/student/day	(Table 4 - 73)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	$L/m^2/day$	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	$L/m^2/day$	(Figure 3 - 27)

- NS *is the number of students in elementary, secondary, high school and schools, in general.*
- CHA *is the cooling and heating area in elementary, secondary, high school and schools, in general.*
- IA *is the irrigation area in elementary, secondary, high school and schools, in general.*

4.3.7 University

The analysis of university water consumption comprises seven main micro-components: restroom consumption, irrigation, cooling and heating, kitchen, swimming pool, laundry and a final component which includes all other non-considered uses and any unintentional consumption. These water consumption micro-components are analyzed in section (3.4.7.1).

For the analysis to be meaningful and to obtain comparable figures between different studies and universities, the average water consumption is analyzed in terms of a unit of a potential driver. More specifically, the drivers used to describe normalized water consumption in universities are the floor area, per capita and the number of students. Details of this analysis can be found in section (3.4.7.2). In any case, the large heterogeneity of water consumption in universities should be highlighted, as seen from the high variability of results described by the different authors referenced in the present thesis.

With the data compiled and consolidated from several studies, more detailed relationships and conclusions can be raised to improve the development of a water consumption model in universities.

4.3.7.1 Water consumption micro-components in university

Table 4 - 82 shows the average weight of each water consumption micro-component from all the studies considered in this analysis. This table summarizes the findings and has helped develop simplified and easy to use equations that describe water consumption in universities.

As a result, the sum of the different micro-components' average contribution does not necessarily have to add up exactly 100%. This is because the average contribution specified for a given micro-component (second row in Table 4 - 82) is calculated from the various contributions of all previous studies. In the universities' case, the sum of the contributions of the different uses sums up to 102%. Therefore, the average figures must be normalized so all micro-components' aggregated contribution is exactly 100%. The normalized values of these contributions are presented in row 3.

This table also shows the average daily water consumption in the universities based on the various drivers found in previous literature, as expressed in terms of per capita, floor area, and the number of students.

The normalized figures obtained for each one of these drivers are the following:

- The average figure for the daily water consumption Distribution of *daily per floor area water consumption in a hotel* is 126 L/capita/day, which has been obtained and calculated through a frequency distribution analysis of the data extracted from the different studies (Figure 3 - 83).
- In the same manner, it has been obtained that the average value for the daily water consumption per floor area is 1.07 L/m^2/day (Figure 3 - 84).
- Finally, it has been derived that the average daily water consumption per student is 37 L/student/day (Figure 3 - 85).

Table 4 - 82 Contribution of water consumption micro-components in universities. Average figures and benchmarks

University water consumption micro-components and its unitary parameters.	Restroom	Landscaping	Kitchen	Cooling and heating	Other	Laundry	Swimming Pool	Total
Average percentage of water consumption micro-components.	33%	17%	23%	20%	5%	3%	1%	102%
University water consumption micro-components.	32%	17%	22%	20%	3%	1%	5%	100%
Average daily water consumption, based on the per capita (L/capita/day).	40.3	21.4	25.2	27.7	6.3	3.8	1.2	126
Average daily water consumption, based on the floor area (L/m^2/day).	0.34	0.18	0.24	0.21	0.03	0.01	0.05	1.07
Average daily water consumption, based on the number of students (L/student/day).	11.84	6.29	8.14	7.4	1.11	0.36	1.85	37

4.3.7.2 Model assumptions in describing water consumption in university

From Table 4 - 82, the following equations can be derived based on the assumption that university water consumption can be obtained as a function of the main drivers previously mentioned: floor area of the university, per capita and the number of students. The influence of these drivers and how their contribution may affect water consumption in a university needs to be reflected in the university water model to be applied.

University water consumption consists of different micro-components, as discussed in detail in section (3.4.7.1). Considering the previously mentioned drivers, it seems reasonable to assume that the water consumption due to irrigation, cooling, and heating should only be related to their coverage area. Therefore, if the irrigation area (IA) and the cooling and heating area (CHA) are known, the water consumption of these components can be easily determined utilizing the average daily water consumption in the cooling and heating area (CHA) - 0.9 L/m^2/day (Figure 3 - 33) – and the average daily water consumption in irrigation area (IA) - 3.5 L/m^2/day (Figure 3 - 27). But, if the irrigation area (IA) and the cooling and heating area (CHA) are unknown, the water consumption of these uses needs to be estimated as a function ratio in terms of other drivers' expression functions.

4.3.7.3 Daily university water consumption equations

Daily university water consumption equations can be developed based on the per capita (PC) and the number of students (NS) when the cooling and heating area (CHA) and irrigation area (IA) are known and unknown.

4.3.7.3.1 Daily university water consumption equations based on the per capita

1. *Total Water Consumption (TWC) in the university based on Per Capita (PC) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known.*

$$TWC_{university} = PC \cdot (C_{PC} + C_{CHA} \cdot (1/R_{CHA}^{PC}) + C_{IA} \cdot (1/R_{IA}^{PC}))$$

Where:

- *C_{XXX} coefficients, where the subindex C_{PC}, C_{CHA} and C_{IA} represents the average unitary university water consumption based on the parameters expressed in Table 4 – 83.*

Table 4 – 83 Unitary university water consumption based on per capita when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{PC}	The average unitary university water consumption based on the per capita. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and swimming pool.	76.8	L/capita/day	(Table 4 - 82)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *PC is the per capita in the university, which include all students, faculty, staff, and visitor, and can be calculated from equations based on the available parameters.*

  $PC = NS \cdot R_{NS}^{PC}$
  $PC = FA \cdot R_{FA}^{PC}$

- *R_{YYY}^{XX} coefficient ratio, where the subindex YYY and subindex XX represents the university water consumption (Table 4 - 82), based on the parameters expressed in Table 4 – 84.*

Table 4 – 84 Ratio of university water consumption based on per capita when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{NS}^{PC}	Ratio representing the water consumption based on the number of students to water consumption based on per capita. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and pool.	0.22	Per capita/student
R_{FA}^{PC}	Ratio representing the water consumption based on the university floor area to water consumption based on per capita. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and pool.	0.008	Per capita/m^2
R_{CHA}^{PC}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the per capita when its area is known.	0.03	Per capita/m^2
R_{IA}^{PC}	Ratio representing the average water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the per capita when its area is known.	0.16	Per capita/m^2

2. *Total Water Consumption (TWC) in the university based on Per Capita (PC) when Cooling and Heating area (CHA) and Irrigation area (IA) are unknown*

$$TWC_{university} = C_{PC} \cdot PC + C_{CHA,U} \cdot (PC/R^{PC}_{CHA,U}) + C_{IA,U} \cdot (PC/R^{PC}_{IA,U})$$

Where:

– C_{XXXX} *coefficients where the subindex* C_{PC}*,* $C_{CHA,U}$ *and* $C_{IA,U}$ *represents the unitary university water consumption based on the parameters expressed in Table 4 – 85.*

Table 4 – 85 Unitary university water consumption based on per capita when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.24	$L/m^2/day$	(Table 4 - 82)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	0.18	$L/m^2/day$	(Table 4 - 82)

– R^{XX}_{YYYY} *coefficient ratio, where the subindex YYYY and subindex XX represent university water consumption (Table 4 - 82), based on the parameters expressed in Table 4 – 86.*

Table 4 – 86 Ratio of university water consumption based on per capita when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R^{PC}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the university floor area to water consumption of the cooling and heating area based on the per capita when its area is unknown.	0.009	per capita/m^2
$R^{PC}_{IA,U}$	Ratio representing water consumption of the irrigation area based on the university floor area to water consumption of the irrigation area based on the per capita when its area is unknown.	0.008	per capita/m^2

3. *Total Water Consumption (TWC) in the university based Per Capita (PC) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{university} = C_{PC,T} \cdot PC$$

Where:

- PC *is the per capita in the university, which include all students, faculty, staff, and visitor, and can be calculated from equations based on the available parameters.*
- $C_{PC,T}$ *is total unitary university water consumption based on per capita. The analyzed references estimate it as 126 L/capita/day (Table 4 - 82).*

4.3.7.3.2 Daily university water consumption equations based on the per capita, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the university based on Per Capita (PC), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{university} = C_{PC} \cdot PC + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where:

- C_{XXX} *coefficients, where the subindex* C_{FA}, C_{CHA} *and* C_{IA} *represents the average unitary university water consumption based on the parameters expressed in Table 4 – 87*

Table 4 – 87 Unitary university water consumption based on per capita, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	**Definition**	**Value**	**Unit**	**Reference**
C_{PC}	The average unitary university water consumption based on the per capita. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and swimming pool.	76.8	L/capita/day	(Table 4 - 82)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- PC *is the per capita in the university, which includes all students, faculty, staff, and visitors.*
- CHA *is the cooling and heating area of the university.*
- IA *is the irrigation area of the university.*

4.3.7.3.3 Daily university water consumption equations based on the floor area

1. Total Water Consumption (TWC) in the university based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known

$$TWC_{university} = C_{FA} \cdot FA + C_{CHA} \cdot CHA + C_{IA} \cdot IA$$

Where:

- *C_{XXX} coefficients, where the subindex C_{FA}, C_{CHA} and C_{IA} represent the average unitary university water consumption defined in Table 4 – 88Table 4 - 102.*

Table 4 – 88 Unitary university water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	**Definition**	**Value**	**Unit**	**Reference**
C_{FA}	The average unitary university water consumption based on the floor area. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and swimming pool.	0.7	L/m²/day	(Table 4 - 82)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m²/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m²/day	(Figure 3 - 27)

- *FA is the floor area of the university; and can be calculated from equations based on the parameters available*

  $FA = NS \cdot R_{NS}^{FA}$
  $FA = PC \cdot R_{PC}^{FA}$

- *R_{YYY}^{XXX} coefficient ratio, where the subindex YYY and subindex XXX represent the university water consumption (Table 4 - 82), is based on the parameters expressed in Table 4 – 89.*

Table 4 – 89 Ratio of university water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{NS}^{FA}	Ratio representing the water consumption based on the number of students to water consumption based on the university floor area. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and swimming pool.	0.2	m^2/student
R_{PC}^{FA}	Ratio representing the water consumption based on per capita to water consumption based on the university floor area. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and swimming pool.	118	m^2/per capita

2. *Total Water Consumption (TWC) in the university based on Floor Area (FA) when Cooling and Heating area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{university} = C_{FA} \cdot FA + C_{CHA,U} \cdot FA + C_{IA,U} \cdot FA$$

Where:

– *C_{XXX} coefficients where the subindex C_{FA}, $C_{CHA,U}$ and $C_{IA,U}$ represents the average unitary university water consumption based on the parameters as expressed in Table 4 – 90.*

Table 4 – 90 Unitary university water consumption based on floor area, when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.24	L/m^2/day	(Table 4 - 82)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	0.18	L/m^2/day	(Table 4 - 82)

3. *Total Water Consumption (TWC) in the university based on Floor Area (FA) when the Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{university} = C_{FA,T} \cdot FA$$

Where:

- *FA is the floor area in the university; and can be calculated from the above equations based on available parameters.*
- $C_{FA,T}$ *is total unitary university water consumption based on the university floor area. From the analyzed references, it can be estimated as 1.07 L/m²/day (Table 4 - 82).*

4.3.7.3.4 Daily university water consumption equations based on the number of students

1. *Total Water Consumption (TWC) in the university Number of Students (NS) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{university} = NS \cdot (C_{NS} + C_{CHA} \cdot (1/R_{CHA}^{NS}) + C_{IA} \cdot (1/R_{IA}^{NS}))$$

Where: -

– C_{XXX} *coefficients, where the subindex* C_{NS}*,* C_{CHA} *and* C_{IA} *represents the average unitary university water consumption based on the parameters as expressed in Table 4 – 91.*

Table 4 – 91 Unitary university water consumption based on the number of students when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NS}	The average unitary university water consumption based on the number of students. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and pool.	22.6	L/student/day	(Table 4 - 82)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

– NS *is the number of students in the university; and can be calculated from equations based on available parameters.*

$NS = PC \cdot R_{PC}^{NS}$
$NS = FA \cdot R_{FA}^{NS}$

– R_{YYY}^{XX} *coefficient ratio, where the subindex YYY and subindex XXX represents the university water consumption (Table 4 - 82), based on the parameters expressed in Table 4 – 92.*

Table 4 – 92 Ratio of university water consumption based on the number of students when the cooling and heating areas (CHA) and irrigation areas (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{PC}^{NS}	Ratio representing water consumption based on the university per capita to water consumption based on the number of students. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and pool.	4.41	student/per capita
R_{FA}^{NS}	Ratio representing water consumption based on the university floor area to water consumption based on the number of students. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and pool.	0.03	student/m^2
R_{CHA}^{NS}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the number of students when its area is known.	0.11	student/m^2
R_{IA}^{NS}	Ratio representing water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the number of students when its area is known.	0.55	student/m^2

2. *Total Water Consumption (TWC) in the university based on Number of Students (NS) when Cooling and Heating area (CHA) and Irrigation area (IA) are unknown*

$$TWC_{university} = NS \cdot (C_{NS} + C_{CHA,U} \cdot (1/R^{NS}_{CHA,U}) + C_{IA,U} \cdot (1/R^{NS}_{IA,U}))$$

Where:

- C_{XXX} *coefficients where the subindex* C_{FA}*,* $C_{CHA,U}$ *and* $C_{IA,U}$ *represents the average unitary university water consumption based on the parameters as expressed in Table 4 – 93.*

Table 4 – 93 Unitary university water consumption based on the number of students when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.24	$L/m^2/day$	(Table 4 - 82)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	0.18	$L/m^2/day$	(Table 4 - 82)

- R^{XX}_{YYYY} *coefficient ratio, where the subindex YYYY and subindex XX represents the university water consumption (Table 4 - 82), based on the parameters expressed in Table 4 - 94.*

Table 4 - 94 Ratio of university water consumption based on the number of students when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R^{NS}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the university's floor area to water consumption of the cooling and heating area based on the number of students when its area is unknown.	0.02	$student/m^2$
$R^{NS}_{IA,U}$	Ratio representing water consumption of the irrigation area based on the university floor area to water consumption of the irrigation area based on the number of students when its area is unknown.	0.03	$student/m^2$

3. *Total Water Consumption (TWC) in the university based on Number of Students (NS) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{university} = C_{NS,T} \cdot NS$$

Where:

- NS *is the number of students in the university; and can be calculated from the above equations based on available parameters.*
- $C_{NS,T}$ *is total unitary university water consumption based on the number of students. The analyzed references estimate it as 37 L/student/day (Table 4 - 82).*

4.3.7.3.5 Daily university water consumption equations based on the number of students, cooling and heating area and irrigation Area

1. *Total Water Consumption (TWC) in the university Number of Students (NS), Cooling and Heating Area (CHA) and Irrigation Area (IA).*

$$TWC_{university} = C_{NS} \cdot NS + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where: -

- C_{XXX} *coefficients, where the subindex* C_{NS}, C_{CHA} *and* C_{IA} *represents the average unitary university water consumption based on the parameters expressed in Table 4 - 95.*

Table 4 - 95 Unitary university water consumption based on the number of students, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{NS}	The average unitary university water consumption based on the number of students. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and pool.	22.6	L/student/day	(Table 4 - 82)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	$L/m^2/day$	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	$L/m^2/day$	(Figure 3 - 27)

- NS *is the number of students in the university.*
- CHA *is the cooling and heating area in the university.*
- IA *is the irrigation area in the university.*

4.3.8 Hospital

The analysis of water consumption in hospitals comprises seven main micro-components: restroom consumption, irrigation, cooling and heating, kitchen, medical processes, laundry, and a final component which includes all other non-considered uses and unintentional consumption. These water consumption micro-components are analyzed in section (3.4.8.1).

For the analysis to be meaningful and to obtain comparable figures between different studies and hospitals, the average water consumption is analyzed in terms of a unit of a potential driver. More specifically, the drivers used to describe normalized water consumption in hospitals are the floor area, per capita and the number of beds. Details of this analysis can be found in section (3.4.1.3). In any case, the large heterogeneity of water consumption in hospitals should be highlighted, as seen from the high variability of results described by the different authors referenced in the present thesis.

With the data compiled and consolidated from several studies, more detailed relationships and conclusions can be raised to improve the development of a water consumption model in hospitals.

4.3.8.1 Water consumption micro-components in hospital

Table 4 - 96 shows the average weight of each water consumption micro-component from all the studies considered in this analysis. This table summarizes the findings and has helped develop simplified and easy to use equations that describe water consumption in hospitals.

As a result, the sum of the different micro-components' average contribution does not necessarily have to add up exactly 100%. This is because the average contribution specified for a given micro-component (second row in Table 4 - 4) is calculated from the various contributions of all previous studies. In the hospitals case, the sum of the contributions of the different uses sums up to 109%. Therefore, the average figures must be normalized so all micro-components' aggregated contribution is exactly 100%. The normalized values of these contributions are presented in row 3.

This table also shows the average daily water consumption in hospitals based on the various drivers found in previous literature, as expressed in terms of the floor area, per capita and the number of beds.

The normalized figures obtained for each one of these drivers are the following:

- The average figure for the daily water consumption Distribution of *daily per floor area water consumption in a hotel* is 528 L/capita/day, which has been obtained and calculated through a frequency distribution analysis of the data extracted from the different studies (Figure 3 - 88).
- In the same manner, it has been obtained that the average value for the daily water consumption per floor area is 4.4 L/m^2/day (Figure 3 - 89).
- Finally, it has been derived that the average daily water consumption per bed is 691 L/bed/day (Figure 3 - 90).

Table 4 - 96 Contribution of water consumption micro-components in hospitals. Average figures and benchmarks

Hospital water consumption micro-components and its unitary parameters.	Restrooms	Landscaping	Kitchen	Cooling and heating	Other/un-accounted	Laundry	Medical processes	Total
Average percentage of water consumption micro-components.	35%	9%	7%	19%	15%	7%	17%	109%
Hospital water consumption micro-components.	32%	8%	6%	17%	14%	6%	16%	100%
Average daily water consumption in hospital based on per capita (L/capita/day).	170	44	34	92	73	34	82	528
Average daily water consumption, based on the floor area (L/m^2/day).	1	0.4	0.28	0.8	0.61	0.28	0.69	4.4
Average daily water consumption, based on the number of beds (L/bed/day).	222	57	44	120	95	44	108	691

4.3.8.2 Model assumptions in describing water consumption in hospitals

From Table 4 - 96, the following equations can be derived based on the assumption that hospital water consumption can be obtained as a function of the main drivers previously mentioned: hospital floor area, per capita and the number of beds. The influence of these drivers and how their contribution may affect water consumption in a hospital must be reflected in the hospital water model to be applied.

Hospital water consumption consists of different micro-components, as discussed in detail in section (3.4.8.1). Considering the previously mentioned drivers, it seems reasonable to assume that the water consumption due to irrigation, cooling, and heating should only be related to their coverage area. Therefore, if the irrigation area (IA) and the cooling and heating area (CHA) are known, the water consumption of these components can be easily determined utilizing the average daily water consumption in the cooling and heating area (CHA) - 0.9 L/m^2/day (Figure 3 - 33) - and the average daily water consumption in irrigation area (IA) - 3.5 L/m^2/day (Figure 3 - 27). But, if the irrigation area (IA) and the cooling and heating area (CHA) are unknown, the water consumption of these uses needs to be estimated as a function ratio in terms of other drivers' expression functions.

4.3.8.3 Daily hospital water consumption equations

Daily hospital water consumption equations can be developed based on the per capita (PC), the floor area (FA), the number of beds (NB) and the number of beds (NB) when cooling and heating area (CHA) and irrigation area (IA) are known and unknown.

4.3.8.3.1 Daily hospital water consumption equations based on the per capita

1. *Total Water Consumption (TWC) in the hospital based on Per Capita (PC) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known.*

$$TWC_{hospital} = PC \cdot (C_{PC} + C_{CHA} \cdot (1/R_{CHA}^{PC}) \; + \; C_{IA} \cdot (1/R_{IA}^{PC}))$$

Where: -

- *C_{XXX} coefficients, where the subindex C_{PC}, C_{CHA} and C_{IA} represents the average unitary hospital water consumption based on the parameters expressed in Table 4 - 97.*

Table 4 - 97 Unitary hospital water consumption based on per capita when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{PC}	The average unitary hospital water consumption based on the per capita. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and medical processes.	392	L/capita/day	(Table 4 - 96)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *PC is the per capita in the hospital, including all employees, staff, patients, physicians, nurses, and pharmacists, which can be calculated from the equations based on available parameters.*

  $PC = NB \cdot R_{NB}^{PC}$
  $PC = FA \cdot R_{FA}^{PC}$

- *R_{YYY}^{XXX} coefficient ratio, where the subindex YYY and subindex XXX represents the hospital water consumption (Table 4 - 96), based on the parameters expressed in Table 4 - 98.*

Table 4 - 98 Ratio of hospital water consumption based on per capita when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{NB}^{PC}	Ratio representing water consumption based on the number of beds to water consumption based on the per capita. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and medical processes.	1.3	Per capita/bed
R_{FA}^{PC}	Ratio representing water consumption based on the hospital floor area to water consumption based on the per capita. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and medical processes.	0.008	Per capita/m^2
R_{CHA}^{PC}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the per capita when its area is known.	0.01	Per capita/m^2
R_{IA}^{PC}	Ratio representing the average water consumption of irrigation area (Figure 3 - 27) to water consumption of the irrigation area based on the per capita when its area is known.	0.08	Per capita/m^2

2. *Total Water Consumption (TWC) in the hospital based on Per Capita (PC) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{hospital} = PC \cdot (C_{PC} + C_{CHA,U} \cdot (1/R^{PC}_{CHA,U}) + C_{IA,U} \cdot (1/R^{PC}_{IA,U}))$$

Where:

– *C_{XXXX} coefficients where the subindex C_{PC}, $C_{CHA,U}$ and $C_{IA,U}$ represents the average unitary hospital water consumption based on the parameters expressed in Table 4 - 99.*

Table 4 - 99 Unitary hospital water consumption based on per capita when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when it is unknown.	0.8	L/m^2/day	(Table 4 - 96)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when it is unknown.	0.4	L/m^2/day	(Table 4 - 96)

– *R^{XX}_{YYYY} coefficient ratio, where the subindex YYYY and subindex XX represents the hospital water consumption (Table 4 - 96), based on the parameters expressed in Table 4 - 100.*

Table 4 - 100 Ratio of hospital water consumption based on per capita when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R^{PC}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the hospital floor area to water consumption of the cooling and heating area based on the per capita when its area is unknown.	0.008	per capita/m^2
$R^{PC}_{IA,U}$	Ratio representing water consumption of the irrigation area based on the hospital floor area to water consumption of the irrigation area based on the per capita when its area is unknown.	0.009	per capita/m^2

3. *Total Water Consumption (TWC) in the hospital based on Per Capita (PC) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{hospital} = C_{PC,T} \cdot PC$$

Where:

- PC *is the per capita in hospital, includes all employees, staff, and patients, including patients, physicians, nurses, pharmacists, and allied health personnel, and can be calculated from equations based on available parameters.*
- $C_{PC,T}$ *is the total unitary hospital water consumption based on the per capita. The analyzed references estimate it as 528 L/capita/day (Table 4 - 96).*

4.3.8.3.2 Daily hospital water consumption equations based on the per capita, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the hospital based on Per Capita (PC), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{hospital} = C_{PC} \cdot PC + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where: -

– *C_{XXX} coefficients, where the subindex C_{PC}, $C_{CHA,U}$ and $C_{IA,U}$ represents the average unitary hospital water consumption based on the parameters expressed in Table 4 - 101.*

Table 4 - 101 Unitary hospital water consumption based on per capita, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{PC}	The average unitary hospital water consumption based on the per capita. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and medical processes.	392	L/capita/day	(Table 4 - 96)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	$L/m^2/day$	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	$L/m^2/day$	(Figure 3 - 27)

– *PC is the per capita in the hospital, including all employees, staff, patients, physicians, nurses, and pharmacists, which can be calculated from the equations based on available parameters.*

– *CHA is the cooling and heating area in the hospital.*

– *IA is the irrigation area in the hospital.*

4.3.8.3.3 Daily hospital water consumption equations based on the floor area

1. *Total Water Consumption (TWC) in the hospital based on Floor Area (FA) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{hospital} = C_{FA} \cdot FA + C_{CHA} \cdot CHA + C_{IA} \cdot IA$$

Where:

- *C_{XXX} coefficients, where the subindex C_{FA}, C_{CHA} and C_{IA} represents the average unitary hospital water consumption based on the parameters expressed in Table 4 - 102.*

Table 4 - 102 Unitary hospital water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{FA}	The average unitary hospital water consumption based on the floor area. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and medical processes.	3.3	$L/m^2/day$	(Table 4 - 96)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	$L/m^2/day$	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	$L/m^2/day$	(Figure 3 - 27)

- *FA is the floor area in the hospital and can be calculated from the equations based on available parameters.*

  FA = NB $\cdot R_{NB}^{FA}$
  FA = PC $\cdot R_{PC}^{FA}$

- *R_{YY}^{XX} coefficient ratio, where the subindex YY and subindex XX represents the hospital water consumption (Table 4 - 96), based on the parameters expressed in Table 4 - 104.*

Table 4 - 103 Ratio of hospital water consumption based on floor area when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{NB}^{FA}	Ratio representing water consumption based on the number of beds to water consumption based on the hospital floor area. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and medical processes.	157	m^2/bed
R_{PC}^{FA}	Ratio representing water consumption based on the per capita to water consumption based on the hospital floor area. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and medical processes.	120	m^2/per capita

2. *Total Water Consumption (TWC) in the hospital based on Floor Area (FA) per square meter when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{hospital} = FA \cdot (C_{FA} + C_{CHA,U} + C_{IA,U})$$

Where:

– *C_{XXX} coefficients where the subindex C_{FA}, C_{CHA} and C_{IA} represents the average unitary hospital water consumption based on the parameters expressed in Table 4 - 104.*

Table 4 - 104 Unitary hospital water consumption based on floor area, when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when it is unknown.	0.8	L/m^2/day	(Table 4 - 96)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when it is unknown.	0.4	L/m^2/day	(Table 4 - 96)

3. *Total Water Consumption (TWC) in the hospital based on Floor Area (FA) per square meter when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{hospital} = C_{FA,T} \cdot FA$$

Where:

– *FA is the floor area in the hospital; and can be calculated from the above equations based on available parameters*

– *$C_{FA,T}$ is total unitary hospital water consumption based on the hospital floor area. From the references analyzed, it can be estimated as 4.4 L/m^2/day (Table 4 - 96).*

4.3.8.3.4 Daily hospital water consumption equations based on the number of beds

1. *Total Water Consumption (TWC) in the hospital Number of Beds (NB) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known*

$$TWC_{hospital} = NB \cdot (C_{NB} + C_{CHA} \cdot (1/R_{CHA}^{NB}) + C_{IA} \cdot (1/R_{IA}^{NB}))$$

Where:

– C_{XXX} *coefficients, where the subindex* C_{NB}, C_{CHA} *and* C_{IA} *represents the average unitary hospital water consumption based on the parameters expressed in Table 4 - 105.*

Table 4 - 105 Unitary hospital water consumption based on the number of beds when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Name	Definition	Value	Unit	Reference
C_{NB}	The average unitary hospital water consumption based on the number of beds. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and medical processes.	513	L/bed/day	(Table 4 - 96)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	$L/m^2/day$	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	$L/m^2/day$	(Figure 3 - 27)

– NB *is the number of hospital beds; and can be calculated from the equations based on available parameters.*

$NB = PC \cdot R_{PC}^{NB}$
$NB = FA \cdot R_{FA}^{NB}$

– R_{YYY}^{XX} *coefficient ratio, where the subindex YYY and subindex XX represents the hospital water consumption (Table 4 - 96), based on the parameters expressed in Table 4 - 106.*

Table 4 - 106 Ratio of hospital water consumption based on the number of beds when cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{PC}^{NB}	Ratio representing water consumption based on the per capita to water consumption based on the number of beds. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and medical processes.	0.76	bed/per capita
R_{FA}^{NB}	Ratio representing water consumption based on hospital floor area to water consumption based on the number of beds. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and medical processes.	0.006	bed/m^2
R_{CHA}^{NB}	Ratio representing water consumption of the cooling and heating area (Figure 3 - 33) to the water consumption of the cooling and heating area based on the number of beds when its area is known.	0.007	bed/m^2
R_{IA}^{NB}	Ratio representing the average water consumption of the irrigation area (Figure 3 - 27) to the water consumption of the irrigation area based on the number of beds when its area is known.	0.06	bed/m^2

2. *Total Water Consumption (TWC) in the hospital based on Number of Beds (NB) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown*

$$TWC_{hospital} = NB \cdot (C_{NB} + C_{CHA,U} \cdot (1/R^{NB}_{CHA,U}) + C_{IA,U} \cdot (1/R^{NB}_{IA,U}))$$

Where:

- C_{XXX} *coefficients where the subindex* C_{FA}, $C_{CHA,U}$ *and* $C_{IA,U}$ *represents the average unitary hospital water consumption based on the parameters expressed in Table 4 - 107.*

Table 4 - 107 Unitary hospital water consumption based on the number of beds when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when its area is unknown.	0.8	$L/m^2/day$	(Table 4 - 96)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when its area is unknown.	0.4	$L/m^2/day$	(Table 4 - 96)

- R^{XX}_{YYYY} *coefficient ratio, where the subindex YYYY and subindex XX represents hospital water consumption (Table 4 - 96), based on the parameters expressed in Table 4 - 108 daily hospital water consumption equations.*

Table 4 - 108 Ratio of hospital water consumption based on the number of beds when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R^{NB}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the hospital floor area to water consumption of the cooling and heating area based on the number of beds when its area is unknown.	0.006	bed/m^2
$R^{NB}_{IA,U}$	Ratio representing water consumption of the irrigation area based on the hospital floor area to water consumption of the irrigation area based on the number of beds when its area is unknown.	0.007	bed/m^2

3. *Total Water Consumption (TWC) in the hospital based on Number of Beds (NB) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{hospital} = C_{NB,T} \cdot NB$$

Where:

- NB *is the number of beds in the hospital; and can be calculated from the above equations based on available parameters.*
- $C_{NB,T}$ *is total unitary hospital water consumption based on the number of beds. The analyzed references estimate it as 619 L/bed/day (Table 4 - 96).*

4.3.8.3.5 Daily hospital water consumption equations based on the number of beds, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the hospital based on Number of Beds (NB), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{hospital} = C_{NB} \cdot NB + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where: -

- *C_{XXX} coefficients, where the subindex C_{NB}, C_{CHA} and C_{IA} represents the average unitary hospital water consumption based on the parameters expressed in Table 4 - 109.*

Table 4 - 109 Unitary hospital water consumption based on the number of beds, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{NB}	The average unitary hospital water consumption based on the number of beds. This consumption includes restrooms, kitchen, others/unaccounted consumption, laundry, and medical processes.	513	L/bed/day	(Table 4 - 96)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- *NB is the number of beds in the hospital.*
- *CHA is the cooling and heating area in the hospital.*
- *IA is the irrigation area in the hospital.*

4.3.9 Mosques

The water consumption analysis in mosques comprises three main micro-components: restrooms and ablution consumption, irrigation and cooling and heating. These water consumption micro-components are analyzed in section (3.4.9.1).

For the analysis to be meaningful and to obtain comparable figures between different studies and mosques, the average water consumption is analyzed in terms of a unit of the potential driver. More specifically, the drivers used to describe normalized water consumption in mosques are the number of mosques and worshippers. Details of this analysis can be found in section (3.4.9.2). In any case, the large heterogeneity of water consumption in mosques should be highlighted, as seen from the high variability of results described by the different authors referenced in the present thesis.

With the data compiled and consolidated from several studies, more detailed relationships and conclusions can be raised to improve the development of a water consumption model in mosques.

4.3.9.1 Water consumption micro-components in mosques

Table 4 - 110 shows the average weight of each water consumption micro-component from all the studies considered in this analysis. This table summarizes the findings and has helped develop simplified and easy to use equations describing mosques' water consumption.

This table also shows the average daily water consumption in the mosques based on the various drivers found in previous literature, as expressed in the number of mosques and worshippers.

The normalized figures obtained for each one of these drivers are the following:

- The average daily water consumption per mosque figure is 13,081 L/m2/day, obtained and calculated through a frequency distribution analysis of the data extracted from the different studies (
- Figure 3 - 91).
- In the same manner, it has been obtained that the average value for the Distribution of daily per guest water consumption *in a hotel* L/worshipper/day (Figure 3 - 92).

Table 4 - 110 Contribution of water consumption micro-components in mosques. Average figures and benchmarks

Mosque water consumption micro-components and its unitary parameters.	Restrooms and ablution	Irrigation	Cooling and heating	Total
Average percentage of water consumption micro-components.	68%	18%	14%	100%
Average daily water consumption, based on the number of mosques (L/mosque/day).	8895.1	2354.6	1831.3	13,081
Average dailyDistribution of daily per worshipper water consumption in a mosque .	19.7	5.2	4.1	29

4.3.9.2 Model assumptions in describing water consumption in mosques

From Table 4 - 110, the following equations can be derived based on the assumption that mosque water consumption can be obtained as a function of the previously mentioned main drivers: the number of mosques and worshippers. The influence of these drivers and their contribution to water consumption in a mosque must be reflected in the mosque water model to be applied.

Mosque water consumption consists of different micro-components, as discussed in detail in section (3.4.9.1). Considering the previously mentioned drivers, it seems reasonable to assume that the water consumption due to irrigation, cooling, and heating should only be related to their coverage area. Therefore, if the irrigation area (IA) and the cooling and heating area (CHA) are known, the water consumption of these components can be easily determined utilizing the average daily water consumption in the cooling and heating area (CHA) - 0.9 L/m²/day (Figure 3 - 33) - and the average daily water consumption in irrigation area (IA) - 3.5 L/m²/day (Figure 3 - 27). But, if the irrigation area (IA) and the cooling and heating area (CHA) are unknown, the water consumption of these uses needs to be estimated as a function ratio in terms of other drivers' expression functions.

4.3.9.3 Daily mosque water consumption equations

Daily mosque water consumption equations can be developed based on the number of mosques (NM) with cooling and heating area (CHA) and irrigation area (IA) and the number of worshippers (NP) with cooling and heating area (CHA) and irrigation area (IA).

4.3.9.3.1 Daily mosque water consumption equations are based on the number of mosques, cooling and heating areas, and irrigation areas

1. *Total Water Consumption (TWC) in the mosque based on Number of Mosques (NM), Cooling and Heating Area (CHA) and Irrigation Area (IA)*

$$TWC_{mosque} = C_{NM} \cdot NM + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where: -

- C_{XXX} *coefficients, where the subindex* C_{NM}, C_{CHA} *and* C_{IA} *represents the average unitary mosque water consumption based on the parameters expressed in Table 4 - 111.*

Table 4 - 111 Unitary mosque water consumption-based number of mosques (NM), cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{NM}	The average unitary mosque water consumption based on the number of mosques. This consumption includes ablution.	8895.1	L/mosque/day	(Table 4 - 110)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- NM *is the number of mosques.*
- CHA *is the cooling and heating area in the mosque.*
- IA *is the irrigation area in the mosque.*

2. *Total Water Consumption (TWC) in the mosque based on Number of Mosques (NM), Cooling and Heating Area (CHA) and Irrigation Area (IA), when Cooling and Heating area (CHA) and Irrigation Area (IA) are known and unknown*

$$TWC_{mosque} = C_{NM} \cdot NM + C_{CHA,U} \cdot (CHA) + C_{IA,U} \cdot (IA)$$

Where:

- C_{XXX} *coefficients where the subindex* C_{NM}, C_{CHA} *and* C_{IA} *represents the average unitary mosque water consumption based on the parameters as expressed in Table 4 - 112.*

Table 4 - 112 Unitary mosque water consumption based on the number of mosques (NM) when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when it is unknown.	0.8	L/m^2/day	(Table 4 - 96)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when it is unknown.	0.4	L/m^2/day	(Table 4 - 96)

- R_{YYY}^{XX} *coefficient ratio, where the subindex YYY and subindex XXXX represents the mosque water consumption (Table 4 - 110), based on the parameters expressed in Table 4 - 113.*

Table 4 - 113 Ratio of mosque water consumption based on the number of mosques (NM) when cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R_{CHA,U}^{NM}$	Ratio representing water consumption of the cooling and heating area based on the mosque floor area to water consumption of the cooling and heating area based on the number of worshippers when its area is unknown.	0.008	per capita/m^2
$R_{IA,U}^{NM}$	Ratio representing water consumption of the irrigation area based on the mosque floor area to water consumption of the irrigation area based on the number of worshippers when its area is unknown.	0.009	per capita/m^2

3. *Total Water Consumption (TWC) in the mosque based on Number of Mosques (NM) when Cooling and Heating area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{mosque} = C_{NM,T} \cdot NM$$

Where:

– $C_{NM,T}$ *is total unitary mosque water consumption based on the number of mosques. The analyzed references estimate it as 13,081 L/mosque/day (Table 4 - 110).*

4.3.9.3.2 Daily mosque water consumption equations based on the number of worshippers, cooling and heating area and irrigation area

1. *Total Water Consumption (TWC) in the mosque based on the Number of Worshippers (NW), Cooling and Heating Area (CHA) and Irrigation Area (IA).*

$$TWC_{mosque} = C_{NW} \cdot NW + C_{CHA} \cdot (CHA) + C_{IA} \cdot (IA)$$

Where: -

- C_{XXX} *coefficients, where the subindex* C_{NW}, C_{CHA} *and* C_{IA} *represents the average unitary mosque water consumption based on the parameters expressed in Table 4 - 114.*

Table 4 - 114 Unitary mosque water consumption based on worshippers, cooling and heating area (CHA) and irrigation area (IA)

Coefficient Name	Definition	Value	Unit	Reference
C_{NP}	The average unitary mosque water consumption based on the number of worshippers. This consumption includes restrooms.	19.7	L/worshipper/day	(Table 4 - 110)
C_{CHA}	The average unitary water consumption in the cooling and heating area.	0.9	L/m^2/day	(Figure 3 - 33)
C_{IA}	The average unitary water consumption in the irrigation area.	3.5	L/m^2/day	(Figure 3 - 27)

- NW *is the number of worshippers in the mosque; and can be calculated from the equations based on available parameters.*

  $NP = \mathrm{FA} \cdot R_{FA}^{NP}$

- CHA *is the cooling and heating area in the mosque.*
- IA *is the irrigation area in the mosque.*
- *FA is the floor area in the mosque.*
- R_{YYY}^{XXX} *coefficient ratio, where the subindex YYY and subindex XXX represents the mosque water consumption (Table 4 - 110), based on the parameters expressed in Table 4 - 115.*

Table 4 - 115 Ratio of mosque water consumption based on the number of worshippers when the cooling and heating area (CHA) and irrigation area (IA) are known

Coefficient Ratio	Definition	Value	Unit
R_{FA}^{NW}	Ratio representing the number of worshippers in the mosque floor area.	1.39	Worshipper/m^2

2. *Total Water Consumption (TWC) in the mosque based on Number of Worshippers (NP), Cooling and Heating area (CHA) and Irrigation area (IA) are unknown*

$$TWC_{mosque} = C_{NW} \cdot NW + C_{CHA,U} \cdot (R^{NP}_{CHA,U}) + C_{IA,U} \cdot (R^{NP}_{IA,U})$$

Where:

– *C_{XXX} coefficients where the subindex C_{FA}, C_{CHA} and C_{IA} represents the average unitary mosque water consumption based on the parameters as expressed in Table 4 - 116.*

Table 4 - 116 Unitary mosque water consumption based on the number of worshippers, cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Name	Definition	Value	Unit	Reference
$C_{CHA,U}$	The average unitary water consumption in the cooling and heating area when it is unknown.	0.8	$L/m^2/day$	(Table 4 - 110)
$C_{IA,U}$	The average unitary water consumption in the irrigation area when it is unknown.	0.4	$L/m^2/day$	(Table 4 - 110)

– *R^{XX}_{YYYY} coefficient ratio, where the subindex YYYY and subindex XXX represents the mosque water consumption (Table 4 - 110), based on the parameters expressed in Table 4 - 117.*

Table 4 - 117 Ratio of mosque water consumption based on the number of worshippers when the cooling and heating area (CHA) and irrigation area (IA) are unknown

Coefficient Ratio	Definition	Value	Unit
$R^{NP}_{CHA,U}$	Ratio representing water consumption of the cooling and heating area based on the mosque floor area to water consumption of the cooling and heating area based on the number of worshippers when their area is unknown.	0.008	$worshipper/m^2$
$R^{NP}_{IA,U}$	Ratio representing water consumption of the irrigation area based on mosque floor area to water consumption of the irrigation area based on the number of worshippers when its area is unknown.	0.009	$worshipper/m^2$

3. *Total Water Consumption (TWC) in the mosque based on Number of Worshippers (NW) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated*

$$TWC_{mosque} = C_{NW,T} \cdot NW$$

Where:

- NW *is the number of worshippers in the mosque; and can be calculated from equations based on available parameters.*
- $C_{NW,T}$ *is total unitary mosque water consumption based on the number of worshippers. From the references analyzed, it can be estimated as 29 L/worshipper/day (Table 4 - 110).*

Chapter 5

MATHEMATICAL MODELS APPLICATION IN MUNICIPAL WATER DEMAND IN KSA

5 MATHEMATICAL MODELS APPLICATION IN MUNICIPAL WATER DEMAND IN KSA

5.1 Introduction

Initially, the demographic forecast is essential for establishing a realistic water demand forecast. The evolution of the population directly affects water consumption for all municipal activities.

The research focused primarily on identifying water consumption in residential and non-residential categories to deliver an actionable water forecast to support its future demand. The detailed knowledge of the water consumption patterns and their data availability leads to planning, forecasting, and conservations in long-term consumption.

The primary purpose is to estimate the municipal water demand (residential and non-residential) in KSA by implementing the municipal water model in chapter four. This will lead to reviewing and assessing the existing population forecast, presenting and analyzing the demographic statistics, and presenting forecast models to develop appropriate municipal water demand forecasting methodologies.

This research will empower KSA to better understand its municipal water consumption and establish sustainable water policies. Therefore, the water demand forecasting model will ensure essential water reliability in the future.

5.2 Population Forecast

5.2.1 Approach

The population forecast approach ensures that all relevant data is used consistently with methodologies used to determine water demand. It is not to redo the existing forecast but to keep with best practices; the CDSI forecast review included a comparison with the most recent United Nations forecast.

As shown in Figure 5 - 1, the general approach to forecasting assumes that the forecast is developed using an internationally accepted model such as DemProj (see Appendix A). In this review, the country's-based population forecast was provided by CDSI, but their high and low scenarios have not been released. The high and low scenarios corresponding to the official CDSI base case forecast can be developed using the UN forecast to reference or use the DemProj model.

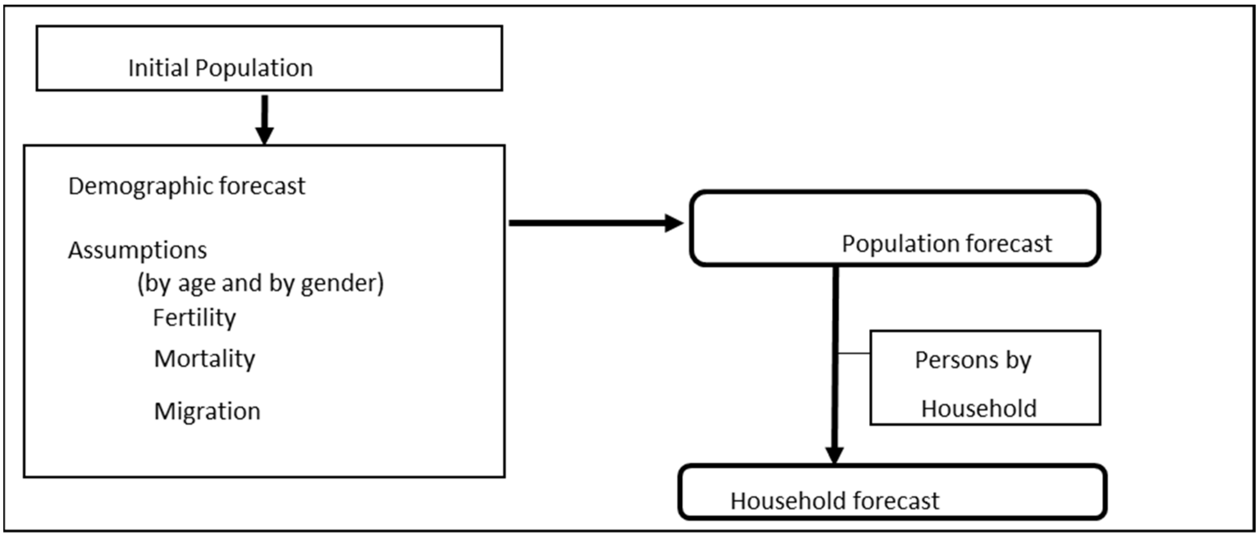


Figure 5 - 1 Components of the population forecast

Water consumption growth in the residential sector is linked strongly with population and household trends. Households and their housing characteristics include the type of houses, the number of persons per household, and the occupancy number.

The linkages between the demographic forecasts and other forecasts essential for developing the water demand forecast are illustrated in Figure 5 - 2.

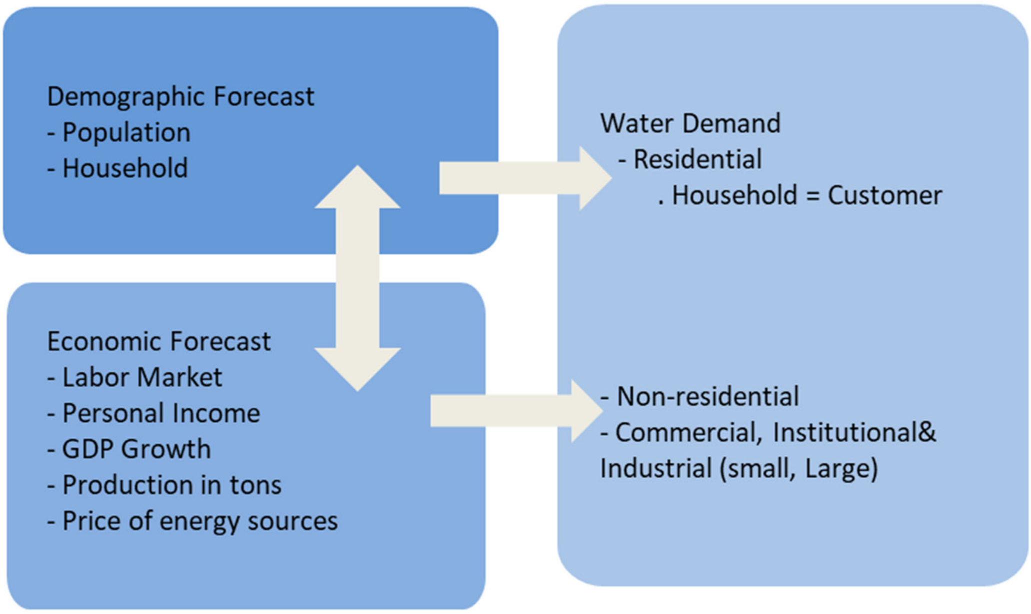


Figure 5 - 2 Link between population, economy, and demand forecasts

The data preparation required for the water demand forecasts followed the below steps.

1. Review of the forecast for the KSA and the thirteen administrative regions

- Review the historical CDSI Census data from 2010, 2004, and 1992 on population and housing to understand the country's population growth and the thirteen regions[1] (CDSI 2010).
- Check with the CDSI population forecast group to obtain additional information on the assumptions used for each forecast component[2].
- Review the High (optimistic) and Low (pessimistic) scenarios to understand these forecasts' assumptions. As the CDSI do generally not publish their high and low forecasts, the review for the high and low forecast was prepared using the United Nations approach (United Nations 2012).

2. Comparison with other forecasts prepared for the country[3]

- Collect population and forecast data from other sources such as the United Nations, World Bank, neighbouring countries, etc.

[1] CDSI website: http://www.cdsi.gov.sa/english/index.php?option=com_docman&task=cat_view&gid=138&Itemid=113

[2] CDSI website: http://www.cdsi.gov.sa/component/content/article/274

[3] United Nation – World Population Prospect, The 2012 Revision, Volume I, Comprehensive Tables
http://esa.un.org/wpp/
http://esa.un.org/wpp/Documentation/pdf/WPP2012_Volume-I_Comprehensive-Tables.pdf

- Compare the collected population and forecast data with the CDSI population and forecast.

3. Preparation of the final population data to be used

- A description of the historical and the base year population trends for the Kingdom and its thirteen regions.
- Prepare alternative scenarios.

5.2.1.1 Data collection

The CDSI was the primary information obtained through direct meetings, official publications and government websites for the population forecast. The bulk of the information was obtained from the CDSI website and included the following:

- Census data (1992, 2004 and 2010) for the population of the country and the thirteen administrative regions;
- Household and housing for the country and the thirteen regions; and,
- Vital statistics for the KSA (births, deaths, etc.), Saudi and non-Saudi, Total Fertility Rate (TFR) and data from other sources of information such as the United Nations Population Prospect were used.

The general demographic characteristics of the KSA are summarized in Table 5 - 1.

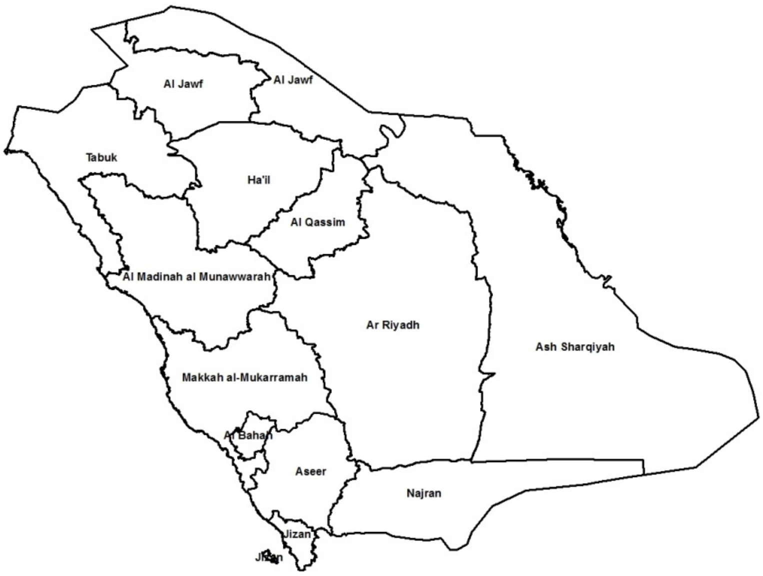
Table 5 - 1 KSA, major demographic indicators

Demographic Indicators	
Population in 2010	**27,136,977**
2004-2010 Annual Growth	**3.0%**
Proportion of Saudi	**69%**
Proportion of Non-Saudi	**31%**
Births (average 2005-2010)	**570,000**
Total Fertility Rate (children/woman, Saudi, 2010)	**3.0**
Death (average 2005-2010)	**88,200**
Expectancy at Birth (in years, both sex, 2010)	**74.3**
Households in 2010	**4,655,127**
2004-2010 Annual Growth	**2.6%**

The thirteen administrative regions as summarized in Table 5 - 2.

Table 5 - 2 KSA, list of the administrative areas from the census

	Administrative Area
1	Al-Riyadh
2	Makkah Al-Mokarramah
3	Al-Madinah Al-Monawarah
4	Al-Qaseem
5	Eastern Region
6	Aseer
7	Tabouk
8	Hail
9	Northern Borders
10	Jazan
11	Najran
12	Al-Baha
13	Al-Jouf



According to the last census held in April 2010, the KSA population totalled 27.1 million people, of which 18.7 million (69%) were Saudi and 8.4 million (31%) were non-Saudi.

The total population grew at an annual rate of 3% between 2004 and 2010, a slight increase compared to the previous census growth rate of 2.5% per annum between 1992 and 2004. During the most recent period, this higher growth rate is due to the 5% growth of the non-Saudi population between 2004 and 2010. During these years, the Saudi population grew at a more modest rate of 2.1% compared to 2.5% between 1992 and 2004. Table 5 - 3 and Figure 5 - 3 present KSA's Saudi and non-Saudi population evolution.

Table 5 - 3 KSA, total population by nationality, households, and census years

Census					
Population	1992	2004	2010	1992-2004	2004-2010
Total	16,948,388	22,678,262	27,136,977	2.5%	3.0%
Saudi – Total	12,310,053	16,527,340	18,707,576	2.5%	2.1%
Non-Saudi Total	4,638,335	6,150,922	8,429,401	2.4%	5.4%
Population Share					
Total	100%	100%	100%		
Saudi – Total	73%	73%	69%		
Non-Saudi Total	27%	27%	31%		
Households					
Total	2,797,144	3,999,011	4,655,127	3.0%	2.6%
Source: Central Department of Statistics & Information (CDSI).					

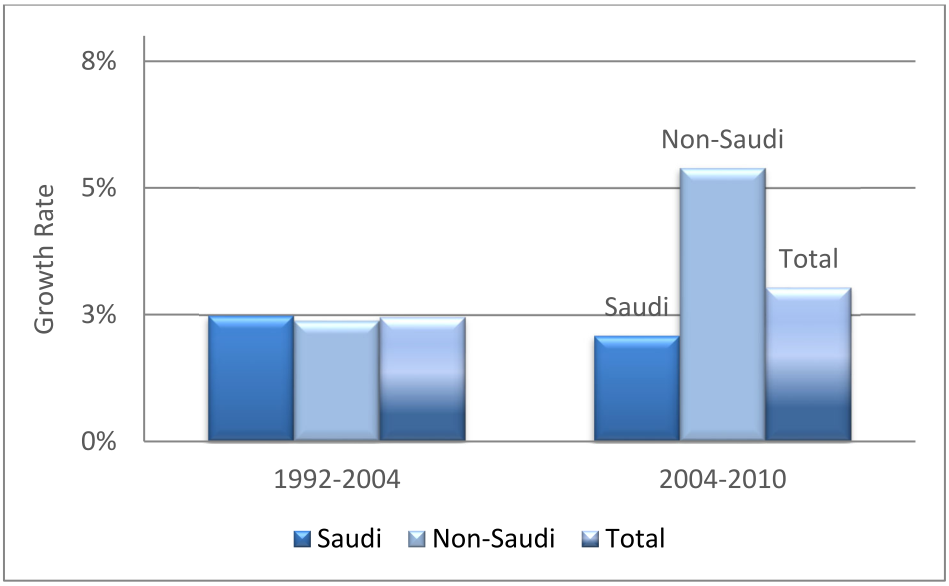


Figure 5 - 3 KSA population growth rate by nationality for the census periods

The total household growth rate has slowed to 2.6% from 3.0% recorded for the previous period (1992 – 2004). The evolution of the Saudi and non-Saudi populations shows historical differences. Largely due to immigration, the proportion of the non-Saudi population has started to increase from 27% in 1992 to 31% in 2010 of the total population (Table 5 - 3 and Figure 5 - 4).

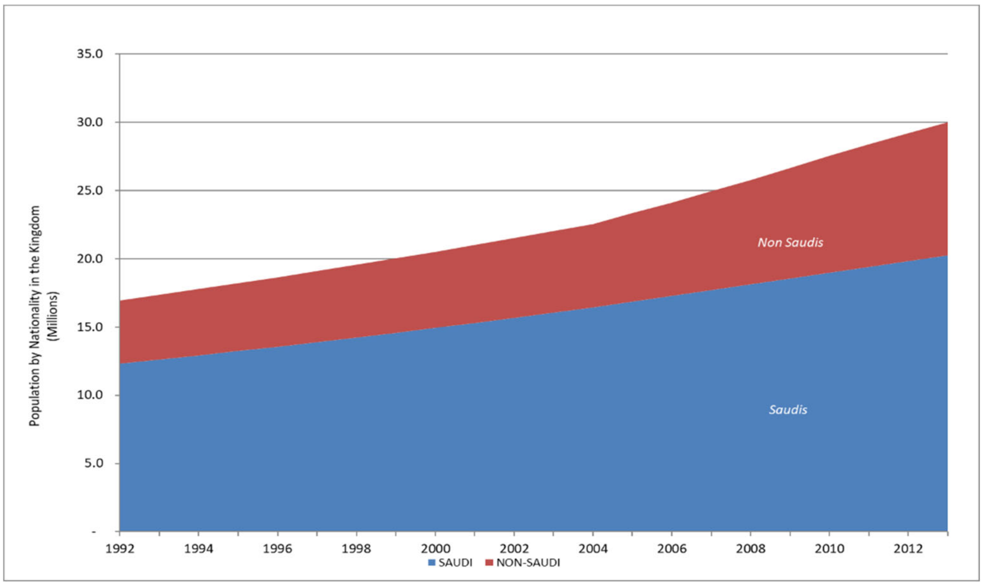


Figure 5 - 4 Evolution of Saudi and Non-Saudi population, 1992-2012

5.2.1.2 Age distribution

For planning purposes, the age structure has implications for employment and water consumption in the future. Table 5 - 9 presents the distribution by age and gender in (CDSI 2007)[4] for the KSA population.

Table 5 - 4 KSA population by nationality, gender and age groups, year 2007

Age Groups	Total			Non - Saudi			Saudi		
	Total	Females	Males	Total	Females	Males	Total	Females	Males
< 1	517116	255755	261361	85583	42074	43509	431533	213681	217852
1 - 4	2232949	1100446	1132503	384269	190744	193525	1848680	909702	938978
5 - 9	2595491	1284262	1311229	437851	211640	226211	2157640	1072622	1085018
10 - 14	2437440	1215613	1221827	363197	178119	185078	2074243	1037494	1036749
15 - 19	2205015	1091466	1113549	280917	139168	141749	1924098	952298	971800
20 - 24	2142928	1029842	1113086	358027	149968	208059	1784901	879874	905027
25 - 29	2305147	988451	1316696	779747	226871	552876	1525400	761580	763820
30 - 34	2373924	947093	1426831	1080254	301120	779134	1293670	645973	647697
35 - 39	2095754	777905	1317849	1035496	246317	789179	1060258	531588	528670
40 - 44	1566299	560793	1005506	701212	134489	566723	865087	426304	438783
45 - 49	1137094	408416	728678	450955	73975	376980	686139	334441	351698
50 - 54	812666	313656	499010	271287	46724	224563	541379	266932	274447
55 - 59	527699	217214	310485	134892	26346	108546	392807	190868	201939
60 - 64	355397	162092	193305	57441	14600	42841	297956	147492	150464
65 - 69	237744	116922	120822	26571	9063	17508	211173	107859	103314
70 - 74	185909	86164	99745	19365	8521	10844	166544	77643	88901
75 - 79	109095	50465	58630	9681	3582	6099	99414	46883	52531
80+	143167	73110	70057	10725	4261	6464	132442	68849	63593
Total	**23980834**	**10679665**	**13301169**	**6487470**	**2007582**	**4479888**	**17493364**	**8672083**	**8821281**

[4] The 2010 census results for population distribution by age and gender are not available yet. Therefore, we have used the most recent data, namely the 2007 demographic survey of population by age and gender.

Figure 5 - 5 presents the age and gender distribution of the population by nationality. The pyramidal shape implies that native Saudis are young, with a median age of 24.7 years. 32% of this population is younger than 15 years old.

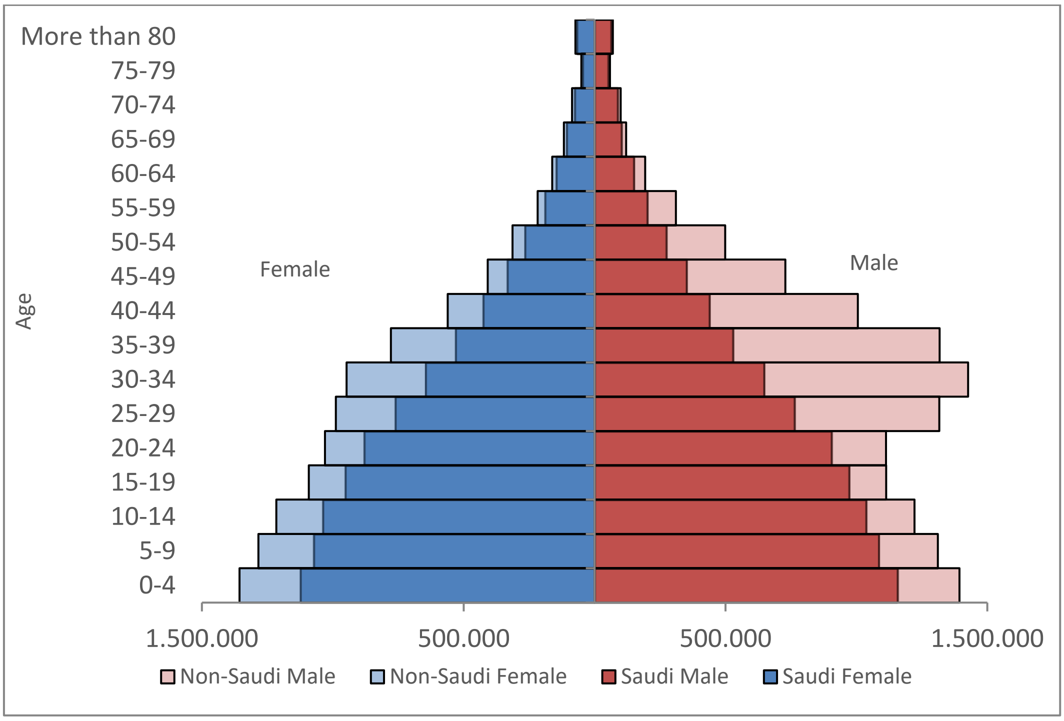


Figure 5 - 5 KSA total population by age group, 2007

The non-Saudi population (light blue and pink) is typical of a temporary community of workers. They are principally men (about 2.2 times larger than the non-Saudi female population) and are generally economically active between ages 25 and 55. Most non-Saudis move to Saudi Arabia for employment, and many of their families do not accompany them.

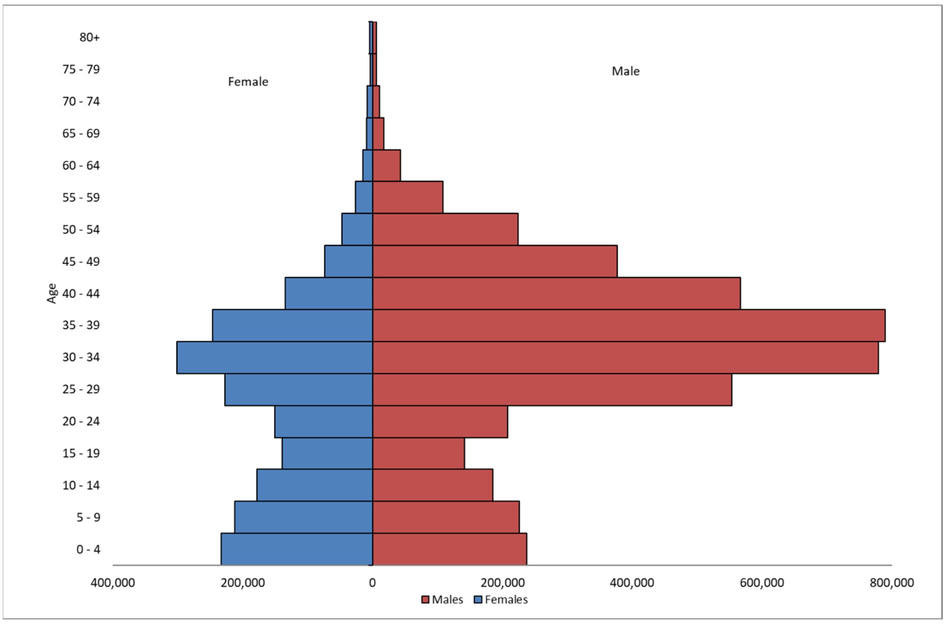


Figure 5 - 6 KSA, Non-Saudi population by age group, 2007

The addition for each age group of the Saudi and non-Saudi population gives the pyramid form in Figures 5 – 7 and 5 - 5.

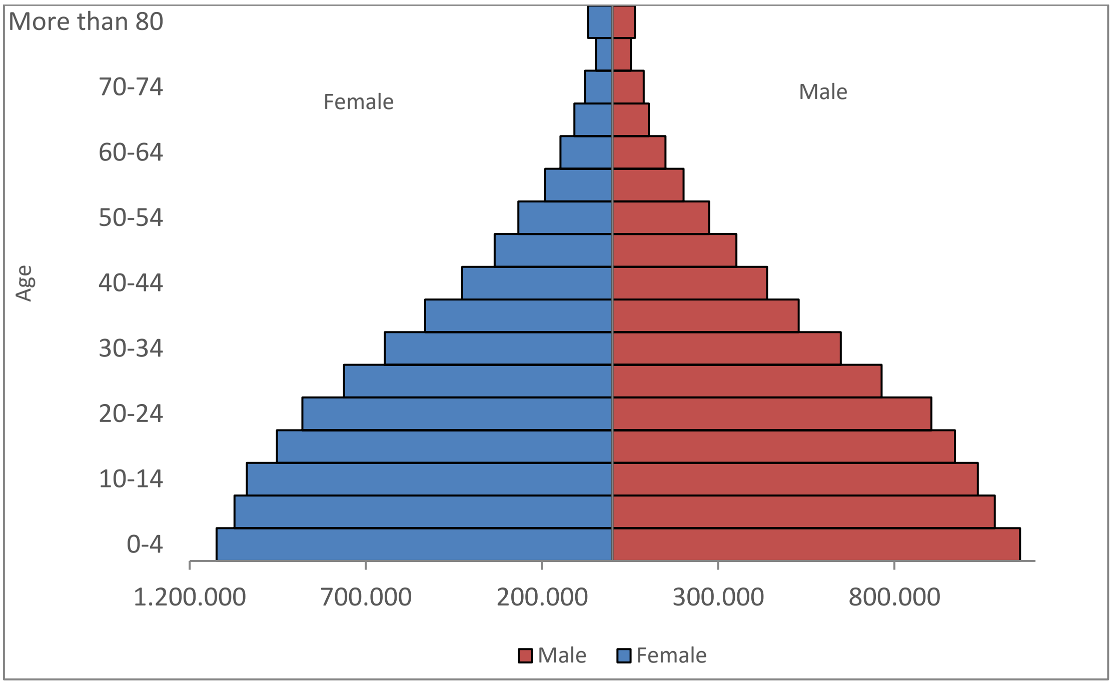


Figure 5 - 7 KSA, Saudi population by age group, 2007

5.2.1.3 Administrative area distribution.

Table 5 - 5 presents the population by nationality and gender for each of the thirteen administrative regions for 2010. The administrative areas with the largest populations are Makkah, with 6.9 million, Riyadh, with 6.8 million; and the Eastern Province, with 4.1 million. Together these three regions account for more than 65% of the KSA.

Table 5 - 5 KSA population by nationality, gender and administrative area, 2010

Administrative Area	Saudi			Non - Saudi			Total		
	Males	Females	Total	Males	Females	Total	Males	Females	Total
Riyadh	2 220 727	2 076 018	4 296 745	1 762 631	717 770	2 480 401	3 983 358	2 793 788	6 777 146
Makkah	2 085 813	2 030 252	4 116 065	1 828 412	970 529	2 798 941	3 914 225	3 000 781	6 915 006
Madinah	635 046	627 466	1 262 512	350 488	164 933	515 421	985 534	792 399	1 777 933
Qaseem	470 490	458 001	928 491	223 403	63 964	287 367	693 893	521 965	1 215 858
Eastern Region	1 498 898	1 392 217	2 891 115	924 771	289 894	1 214 665	2 423 669	1 682 111	4 105 780
Aseer	790 229	800 618	1 590 847	248 055	74 490	322 545	1 038 284	875 108	1 913 392
Tabouk	339 450	321 703	661 153	99 091	31 291	130 382	438 541	352 994	791 535
Hail	242 305	244 899	487 204	84 161	25 779	109 940	326 466	270 678	597 144
Northern Borders	134 622	133 555	268 177	39 550	12 797	52 347	174 172	146 352	320 524
Jazan	559 898	545 197	1 105 095	176 990	83 025	260 015	736 888	628 222	1 365 110
Najran	202 977	199 447	402 424	75 339	27 889	103 228	278 316	227 336	505 652

Baha	169 339	179 297	348 636	48 852	14 400	63 252	218 191	193 697	411 888
Jouf	177 379	171 733	349 112	71 231	19 666	90 897	248 610	191 399	440 009
Total	**9 527 173**	**9 180 403**	**18 707 576**	**5 932 974**	**2 496 427**	**8 429 401**	**15 460 147**	**11 676 830**	**27 136 977**
Preliminary Results of General Population & Housing Census (2010).									

5.2.2 Methodology

Most population forecast models developed by international and national agencies use a classic application of the disaggregated demographic approach (or cohort components approach). This approach is based on coherent links between population parameters and the segmentation by population. It consists of disaggregating the annual population growth by key segments: births, deaths, immigration, and emigration of non-nationals. The population of each segment is then projected annually using age and gender probability ratios.

This demographic forecasting model produces a population forecast by age and gender for each year of the study period. The model uses the approach of cohort-components in which age and gender probabilities are used to project changes in the demographic components affecting population growth (fertility, mortality, and migration). The household forecast is subsequently developed by applying the household formation probabilities for each age group (or the number of persons per household) to the forecast population. An internationally accepted model such as DemProj (see Appendix A for a description) can be used with existing forecasts for comparison purposes and sensitivity studies. The overall approach is shown in Figure 5 - 8.

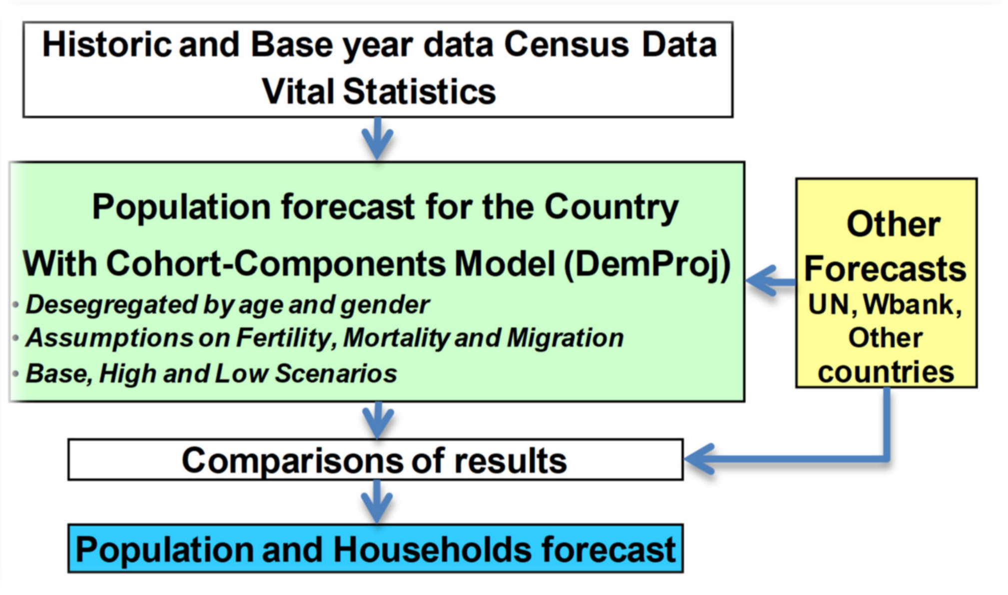


Figure 5 - 8 Population and household projection methodology

Mathematically, the population of most age groups is calculated as the number of people one year younger (see equation below: a-1 younger age group) one year ago (t-1), plus the net migration during the year, minus the number of deaths:

$$\boldsymbol{pop_{a,s,t} = pop_{a-1,s,t-1} + migr_{a-1,s,t-1} - deaths_{a,s,t-1,t}}$$

Where:

$pop_{a,s,t}$ = the population of age group *a* and at time *t.*

$migr_{a-1,s,t-1}$ = the net number of migrants of age group *a-1* at time *t-1.*

$deaths_{a,s,t-1,t}$ = deaths occurring as people age from age group *a-1* at time *t-1* to age *a* at time *t.*

The population younger than one-year-old is calculated as the number of births during the year surviving till the end of the year plus the net migrants:

$$\boldsymbol{pop_{0,s,t} = birth_{s,t} + migr_{0,s,t-1} - deaths_{0,s,t-1,t}}$$

The number of births per year is calculated from the number of women of reproductive age, the TFR, and the age distribution of fertility.

$$\boldsymbol{births_{a,t} = TFR_t \bullet ASFP_{a,t} \bullet pop_{a,female,t}}$$

where:

$births_{a,t}$ = the number of births to women at age *a.*

TFR_t = the total fertility rate at time *t.*

$ASFP_{a,t}$ = the proportion of lifetime fertility at age *a*.

5.3 Existing Population for KSA

Both the CDSI[5] of KSA and the United Nations (UN) – World Population Prospect (United Nations 2012) have developed population-based projections on preliminary results of the 2010 KSA Census, as shown in Figure 5 - 9 and Table 5 - 6.

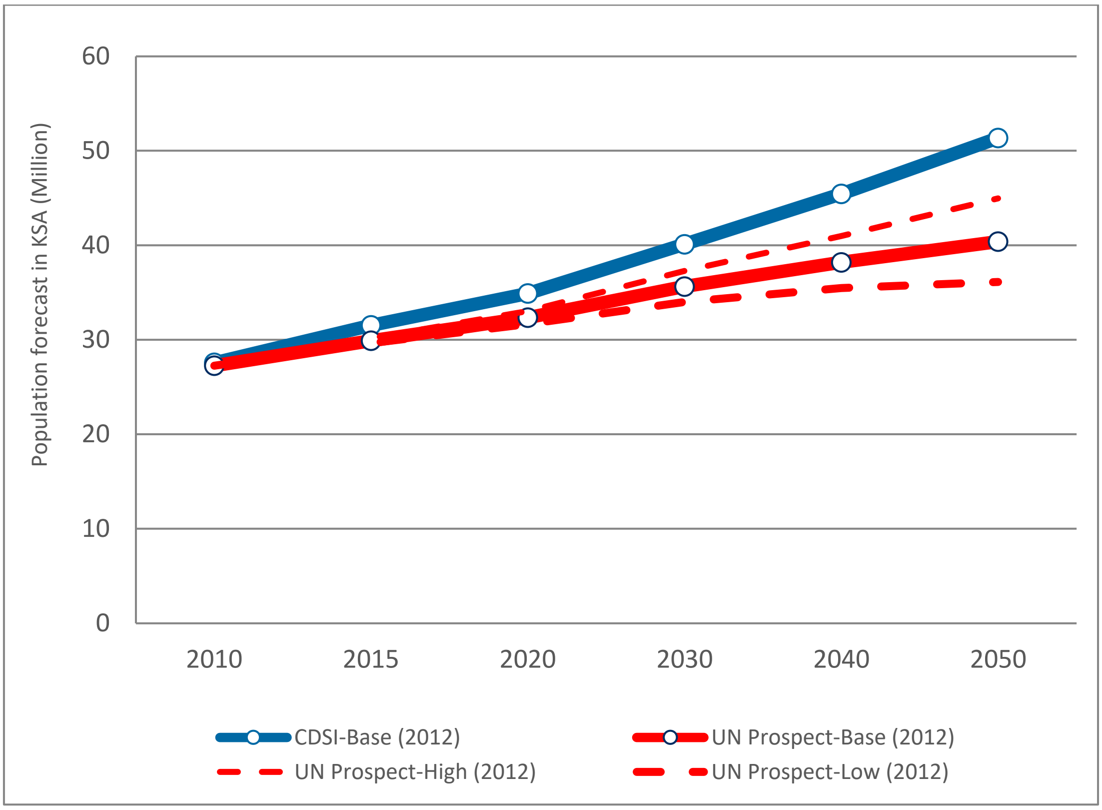


Figure 5 - 9 KSA population forecast – comparison CDSI and UN

Table 5 - 6 shows a significant difference in the base forecasts of about 7 million people in 2040. It should be noted that the UN forecast is based on a methodology applied to all countries. In contrast, the CDSI forecast considers specific detailed factors that the macro-level forecast of the UN may overlook.

Table 5 - 6 KSA Population forecast – comparison of CDSI and UN

Population Forecast – Comparison (millions)							
	2010	CAGR	**2020**	CAGR	**2030**	CAGR	**2040**
CDSI-Base (2012)	27.5	**2.4%**	34.5	**1.4%**	40.1	**1.3%**	45.4
UN Prospect-High (2012)	27.3	**1.9%**	33.0	**1.2%**	37.3	**1.0%**	41.0
UN Prospect-Base (2012)	27.3	**1.7%**	32.3	**1.0%**	35.6	**0.7%**	38.2
UN Prospect-Low (2012)	27.3	**1.5%**	31.6	**0.7%**	34.0	**0.4%**	35.5

[5] CDSI website: http://www.cdsi.gov.sa/english/index.php?option=com_docman&task=cat_view&gid=138&Itemid=113

5.3.1 CDSI population projection

The population forecast data were provided by the CDSI from 2010 to 2050, as shown in Figure 5 - 10, but details on specific assumptions are not yet published. The total population forecast by the administrative region for 2010-2025 is shown in Table 5 - 7. Based on discussions with CDSI, the following assumptions were used for future projections[6]:

1. The methodology is based on a cohort component model that is used around the world.
2. Population projections at the national level for Saudi and non-Saudi are complete, and the projections have been regionalized by administrative area and consider historical trends.
3. The base year for the project is the 2010 census data, which provides projections for 40 years (i.e., till 2050.)
4. Population projections are based on assumptions about the future levels of the total fertility rate (TFR), life expectancy at birth, and international migration. Basic assumptions made in the CDSI forecast appear like the UN assumptions.
5. High and low scenarios have been developed but not released by CDSI.

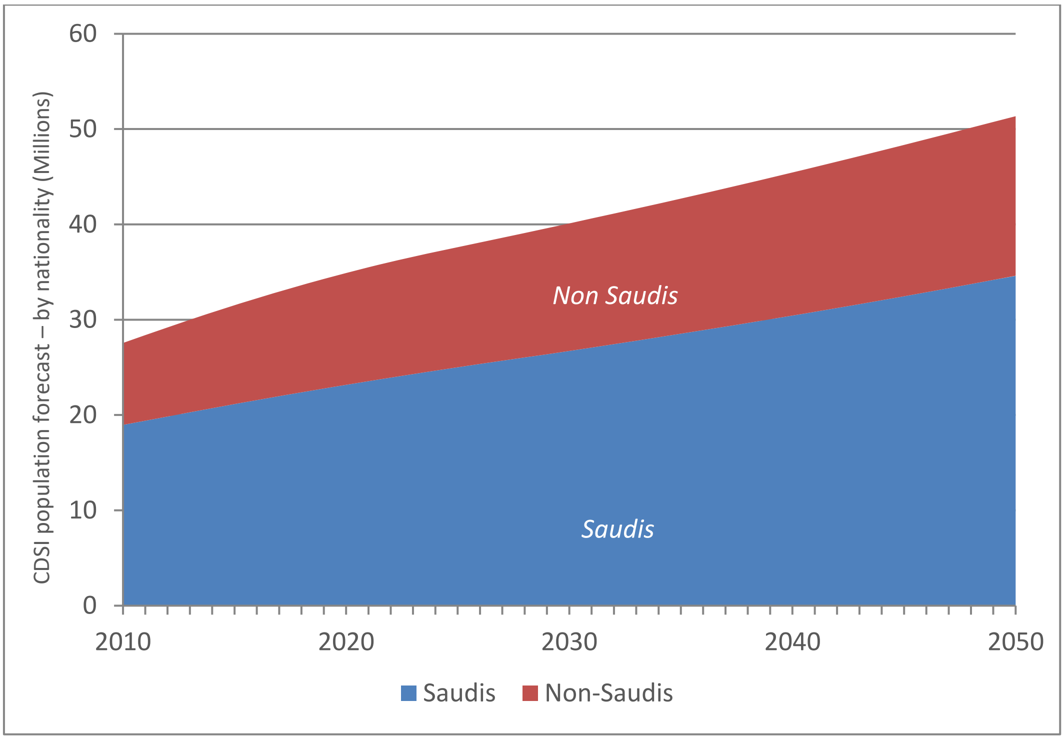


Figure 5 - 10 KSA – CDSI population forecast – by nationality

[6] Most assumptions and information are available to 2050.

5.3.2 CDSI assumptions

The detailed assumptions used to produce the base scenario have been rejected to be provided so far by CDSI. The CDSI base case projection review is based on partial information and information from other sources, such as the UN forecast information, as shown in Table 5 - 7.

Table 5 - 7 KSA-CDSI, total population forecast by administrative area 2010-2025 (Millions)

Administrative Area	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Riyadh	6.89	7.10	7.31	7.52	7.72	7.91	8.10	8.28	8.45	8.61	8.77	8.92	9.07	9.20	2.33	9.45
Makkah	7.03	7.25	7.47	7.69	7.90	8.10	8.29	8.48	8.66	8.83	8.99	9.15	9.29	9.43	9.56	9.69
Madinah	1.81	1.86	1.91	1.96	2.01	2.06	2.11	2.15	2.20	2.24	2.28	2.32	2.36	2.39	2.43	2.46
Qaseem	1.23	1.27	1.30	1.34	1.37	1.40	1.43	1.46	1.49	1.52	1.55	1.58	1.60	1.63	1.65	1.67
Eastern Region	4.17	4.29	4.41	4.53	4.65	4.76	4.87	4.98	5.08	5.18	5.27	5.36	5.45	5.53	5.61	5.68
Aseer	1.94	1.99	2.05	2.10	2.15	2.19	2.24	2.29	2.33	2.38	2.42	2.46	2.50	2.54	2.57	2.61
Tabouk	0.80	0.82	0.85	0.87	0.89	0.91	0.93	0.95	0.96	0.98	1.00	1.02	1.03	1.05	1.06	1.08
Hail	0.61	0.62	0.64	0.65	0.67	0.69	0.70	0.72	0.73	0.74	0.08	0.77	0.78	0.79	0.80	0.82
Northern Borders	0.33	3.34	0.34	0.35	0.36	0.37	0.38	0.38	0.39	0.40	0.41	0.41	0.42	0.42	0.43	0.44
Jazan	1.39	1.42	1.46	1.50	1.53	1.57	1.60	1.64	1.67	1.70	1.73	1.76	1.79	1.82	1.84	1.87
Najran	0.51	0.53	0.54	0.56	0.57	0.58	0.59	0.61	0.62	0.63	0.64	0.65	0.66	0.67	0.68	0.69
Baha	0.42	0.43	0.44	0.45	0.46	0.47	0.48	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.55	0.56
Jouf	0.45	0.46	0.47	0.48	0.49	0.51	0.52	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.59	0.60
Total	**27.56**	**28.40**	**29.20**	**29.99**	**30.77**	**31.52**	**32.25**	**32.95**	**33.63**	**34.28**	**34.90**	**35.50**	**36.06**	**36.61**	**37.12**	**27.61**

5.3.3 Base year population

The 2010 census population distribution by age and gender for Saudi and non-Saudi constitute the base year population. Only partial tables are currently available from the 2010 Census. There is a difference in the initial population (2010) used by both agencies. The UN has used a 2010 population of 300,000 lower than the CDSI, which may have caused this difference to increase over time. The difference in the base year represents 1.1% of the total population, and this proportion is expected to be maintained throughout the forecast period.

5.3.4 Fertility

The Total Fertility Rate (TFR) is the number of live births a woman would have if she survived to age 50 and had children according to the prevailing childbearing pattern at each age group. It is a synthetic measure that expresses the current fertility rate in terms of the average number of live births per woman if the current age-specific fertility rates remained constant and all women survived to age 50. TFR, which translates into annual births, is the main component of KSA's population growth. In 2010, the annual number of births was estimated to be about 600,000 children.

Table 5 - 8 presents the Total Fertility Rates for the Kingdom broken down by nationality from 2004 to 2013. TFR has decreased steadily over the last 30 years, from 7 births per woman in the 1980s to around 3 births per woman in 2010. This is a trend that is very similar to trends observed in many countries throughout the world. It has implications for the total population trend as well as household formation. It also has potential consequences for the labour market and economic growth.

The TFR total for 2010 is around 3.0[7] and has been projected to decrease slowly and reach 1.8 by 2040, according to CDSI representatives. This projection is motivated by the trend observed in KSA and the evolution of many countries in the Middle East (UEA 1.97 and Qatar 2.21 in 2010).

Table 5 - 8 KSA, total fertility rates estimates by nationality (CDSI)

YEAR	TOTAL FERTILITY RATE		
	SAUDI	NON-SAUDI	TOTAL
2004	3,6	2,4	3,3
2005	3,5	2,4	3,3
2006	3,5	2,4	3,2
2007	3,4	2,4	3,2
2008	3,3	2,3	3,1
2009	3,2	2,3	3,0
2010	3,2	2,3	3,0
2011	3,1	2,3	2,9
2012	3,0	2,3	2,9
2013	3,0	2,3	2,8

7 Fertility assumptions have been used by age group at the modelling stage.

These forecasts have similar initial and final points as in the UN projection but may differ in trajectory, especially in the initial years. This may impact the cumulative birth, especially if it applies in the initial years to a more populated women cohort than at the end of the projection trajectory. This could be an explanation of the differences between the two population forecasts.

5.3.5 Mortality

With an estimated 90,000 deaths in 2010, the life expectancy at birth for the total population is 73 years for males and 76 years for females. It is expected to surpass 80 years by 2050. This perspective would be like the UN's assumptions on life expectancy.

5.3.6 International migration

The information from census data indicates substantial immigration from other countries into KSA. Assumptions for future immigration are usually based on past trends and government planning and policies.

There is some uncertainty regarding the net number of migrants as this depends on the number of policies being implemented that would directly affect the number of migrants. The UN population forecast has assumed a decreasing number of annual net migrants over the forecast horizon, from some 60,000 per year for the initial years to zero by the end of their forecast (the year 2100). Based on statistics from the 2010 Census, 70% of the non-Saudi population are men, suggesting that this percentage will be the same in the future. In the case of CDSI, the information on the international migration projection was unavailable.

Based on available data, a summary of the CDSI assumptions for fertility and life expectancy is presented in Table 5 - 9.

Table 5 - 9 KSA- CDSI population forecast, summary of assumptions

<table>
<tr><td colspan="2" rowspan="2">Total Fertility rate (children per woman)[8]</td><td>2010</td><td>2050</td></tr>
<tr><td>3</td><td>1,8</td></tr>
<tr><td colspan="2">Saudi</td><td>3,2</td><td>n/a</td></tr>
<tr><td colspan="2">Non-Saudi</td><td>2,3</td><td>n/a</td></tr>
<tr><td colspan="2">Mortality: Life expectancy at birth (in years)</td><td></td><td></td></tr>
<tr><td rowspan="2">Saudi and non-Saudi</td><td>Males</td><td>73</td><td>81</td></tr>
<tr><td>Females</td><td>76</td><td>83</td></tr>
<tr><td colspan="2">Migration (net migrants by year)</td><td>n/a</td><td>n/a</td></tr>
</table>

[8] See 5 – 10 KSA, Total Fertility Rates Estimates by Nationality (CDSI)

5.3.6.1 United Nations (UN) population prospect 2012[9]

The UN regularly publishes a population prospect for every country. The most recent update of the population forecast for KSA was completed in 2012 and published in 2013. The UN revision has used the preliminary release of the 2010 census data.

Most population forecast models developed by international agencies, including the United Nations, use a classic application of the disaggregated demographic approach (or cohort-components approach). This approach is based on coherent links between population parameters and the segmentation by population. It consists of disaggregating the annual population growth by key segments: births, deaths, immigration, and emigration of non-nationals. Major assumptions and results are summarized in Table 5 - 10 for each population segment and projected using age and gender probability ratios.

Table 5 - 10 KSA-UN population history and forecast 1950-2050

Total Population	**1950**	**1970**	**1990**	**2000**	**2005**	**2010**	**2015**	**2020**	**2030**	**2050**
Total Population (thousands)	3 121	5 803	16 206	20 145	24 690	27 258	29 898	32 341	35 634	40 388
Population density (persons per square km)	1	3	8	9	11	13	14	15	17	19
Median age (years)	19.0	17.9	19.5	21.1	23.7	26.1	28.4	30.8	34.5	41.7
Dependency ratios (per 100)										
Total dependency ratio (a)	83.0	91.6	82.5	72.2	59.7	50.8	45.6	42.3	36.0	52.2
Child dependency ratio (b)	76.9	85.0	77.6	66.2	54.8	46.3	41.2	36.5	26.1	24.2
Old-age dependency ratio (c)	6.1	6.6	4.9	6.0	5.0	4.5	4.4	5.8	9.9	28.0
Rates of population change	**1950-1955**	**1965-1970**	**1985-1990**	**1995-2000**	**2000-2005**	**2005-2010**	**2010-2015**	**2015-2020**	**2025-2030**	**2045-2050**
Annual rate of population change (%)	2.6	3.7	4.0	1.6	4.1	2.0	1.9	1.6	0.8	0.5
Rate of natural increase (per 1,000 population)	24.6	29.9	32.5	25.4	21.0	18.6	16.4	13.8	7.1	4.1
Population doubling time (years) (d)	27	19	18	43	17	35	38	44	85	-
Mortality										
Crude death rate per 1,000 population	23.3	16.8	5.6	4.3	3.8	3.4	3.3	3.3	3.8	7.0
Infant mortality rate (Iq0) per 1,000 live births	202	137	41	23	18	14	11	9	7	4
Under-five mortality (5q0) per 1,000 live births	300	206	54	28	21	15	12	10	7	4
Adult mortality (45q15) per 1,000 (e)	396	329	170	120	102	87	80	75	62	43
Life expectancy at birth (years)	41.9	50.2	67.9	71.6	73.1	74.3	75.4	76.4	78.4	81.8
Male life expectancy at birth (years)	40.0	48.3	66.4	70.1	71.6	72.8	73.8	74.8	76.9	80.9
Female life expectancy at birth (years)	44.1	52.3	69.6	73.7	75.1	76.4	77.5	78.5	80.2	83.0
Life expectancy at age 15 (years)	46.4	49.5	57.1	59.1	60.0	60.8	61.7	62.5	64.1	67.3

[9] Source: see note 7

Life expectancy at age 65 (years)	11.3	11.9	13.7	14.1	14.4	14.8	15.5	16.1	17.3	19.6
Fertility										
Crude birth rate per 1,000 population	47.8	46.7	38.1	29.6	24.7	22.0	19.6	17.1	10.9	11.0
Total fertility (children per woman)	7.17	7.26	6.22	4.51	3.54	3.03	2.68	2.43	2.10	1.78
Sex ratio at birth (males per 100 females)	103	103	103	103	103	103	103	103	103	103
Net reproduction rate (f)	2.22	2.62	2.83	2.12	1.68	1.45	1.29	1.17	1.02	0.87
Mean age childbearing (years)	30.6	30.6	30.9	31.5	31.6	31.6	32.1	32.1	32.1	32.0
Births and deaths										
Number of births (thousands)	798	1 239	2 809	2 868	2 773	2 852	2 804	2 653	1 909	2 202
Number of deaths (thousands)	388	446	415	414	425	441	465	509	661	1 388
Births minus deaths (thousands)	410	793	2 394	2 454	2 348	2 411	2 339	2 143	1 247	814
International migration										
Net number of migrants (thousands)	22	187	538	-877	2 198	157	300	300	180	180
Net migration rate (per 1,000)	1.3	7.1	7.3	-9.1	19.6	1.2	2.1	1.9	1.0	0.9

The UN published three other variant scenarios: a high population scenario, a low population scenario, and a constant fertility scenario. In a high-growth scenario, the KSA population should reach more than 45 million in 2050. In a low growth scenario, the KSA population would reach a 35 million level by 2050. A summary of these projections is shown in Figure 5 - 11 and Table 5 - 11.

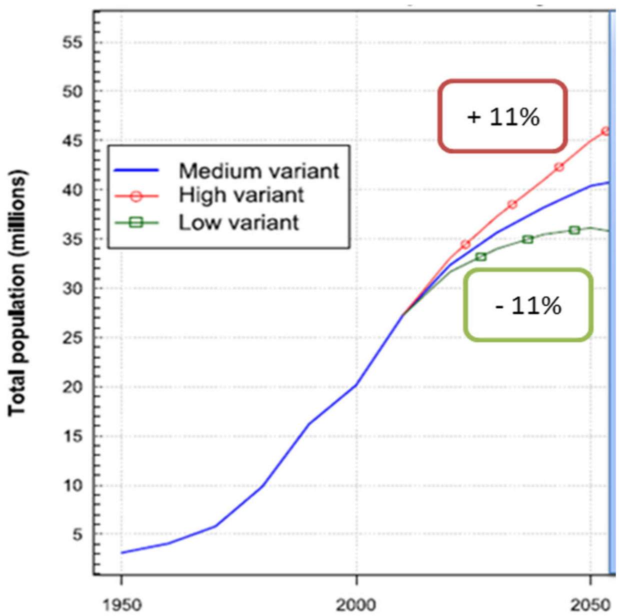


Figure 5 - 11 KSA-UN population forecast – high, base, and low scenarios

Alternative scenarios are built on different assumptions concerning fertility rate, mortality, and net migration. The main driver of these scenarios is the fertility rate. According to the UN projections, in all three scenarios, from high, base, and low, the TFR will continue to decrease.

Table 5 - 11 KSA-UN total fertility rate, high-base-low scenarios 2010-2050

Population	Total Fertility	Population	Total Fertility	Population	Total Fertility
2010-2015	2.93	2010-2015	2.68	2010-2015	2.43
2015-2020	2.83	2015-2020	2.43	2015-2020	2.03
2020-2025	2.74	2020-2025	2.24	2020-2025	1.74
2025-2030	2.60	2025-2030	2.10	2025-2030	1.60
2030-2035	2.48	2030-2035	1.98	2030-2035	1.48
2035-2040	2.39	2035-2040	1.89	2035-2040	1.39
2040-2045	2.32	2040-2045	1.82	2040-2045	1.32
2045-2050	2.28	2045-2050	1.78	2045-2050	1.28
High		Base		Low	

5.3.6.2 Population scenarios

High and low scenarios are usually developed with alternative assumptions about fertility, mortality, and migration components. CDSI provided a base scenario but did not generally release their High and Low scenarios. Without these alternative scenarios, two approaches could be adopted for the analysis. The latter would be preferable should additional details be required for developing alternative scenarios.

The first approach would use the UN High and Low scenario spread around their Base scenario and then apply these deviations around the CDSI base scenario. The population result is a high scenario that attains 49 million in 2040 compared to 45 million in the CDSI base scenario. Alternatively, the low scenario would reach a population level of around 42 million for KSA, as shown in Figure 5 - 12. The problem with this approach is that the basic underlying assumptions need to be consistent, and until they become available, the comparison of assumptions is not possible.

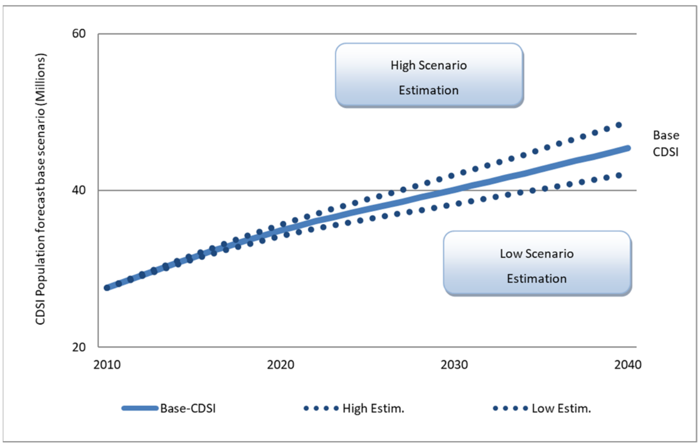


Figure 5 - 12 KSA –CDSI population forecast base scenario – high and low scenarios estimation 2010-2040

5.3.6.3 Area-wise forecast

CDSI has regionalized its total population forecast based on a differential trend evolution in the past and on specific assumptions about residential development for each region of the country.

Table 5 - 12 presents the regional population forecast for selected years. The thirteen regions are the same as defined for the Census.

The forecast suggests that the population of the KSA's three most populous administrative areas, namely, Riyadh, Makkah, and the Eastern Region, will represent approximately 66% of the total population in 2050. This is practically the same share as in 2010 (65%).

Table 5 - 12 KSA-CDSI population forecast 2010-2040 by administrative area

Administrative Area	2010	2040	2010 Share	2040 Share
Riyadh	6 885 455	11 405 830	25%	25%
Makkah	7 026 805	11 679 251	25%	26%
Madinah	1 805 696	2 971 360	7%	7%
Qaseem	1 234 531	2 021 940	4%	4%
Eastern Region	4 170 010	6 865 517	15%	15%
Aseer	1 942 153	3 161 886	7%	7%
Tabouk	803 418	1 307 524	3%	3%
Hail	606 164	988 187	2%	2%
Northern Borders	325 334	529 398	1%	1%
Jazan	1 385 773	2 260 454	5%	5%
Najran	513 339	838 386	2%	2%
Baha	418 050	679 686	2%	1%
Jouf	446 704	729 689	2%	2%
Total	**27 563 432**	**45 439 108**	**100%**	**100%**

5.4 Total number of Housing Units, Average Household Size and Forecast in KSA

5.4.1 Total number of housing units

As shown in Table 5 - 13, the number of housing units in KSA totalled 4,652,162 (CDSI, 2010). Of these housing units, apartment type accounted for 41%, traditional houses for 26% and villas for 18%. Around 60% of the apartments and 45% of the traditional houses are located in Riyadh and Makkah areas—preliminary Results of General Population & Housing Census 1431 A.H (2010 A.D).

Table 5 - 13 KSA housing units by administrative area and housing type, 2010

ADMINISTRATIVE AREAS	HOUSE TYPE						
	Total	Other	Apartment	Floor in Traditional House	Floor in Villa	Villa	Traditional House
Riyadh	1,155,763	117,744	434,533	11,812	159,612	299,243	132,819
Makkah	1,328,840	41,758	719,305	19,035	48,532	100,888	399,322
Jazan	199,625	8612	26,793	2,876	7,763	19,902	133,679
Eastern Province	619,285	22,413	287,402	8,760	35,624	161,911	103,175
Asir	336,065	17,611	88,530	5,607	34,991	58,526	130,800
Qaseem	202,573	19,448	43,925	2,793	25,245	59,410	51,752
Hail	94,223	5,468	13,380	1,012	5,754	24,404	44,205
Madinah	309,171	13,417	158,064	3,351	9,620	26,149	98,570
Baha	75,227	3,731	23,298	2,591	7,666	8,943	28,998
Northern Border	42,708	2,580	9,810	1,252	6,087	14,381	8,598
Tabuk	133,156	5,813	61,762	1,835	10,320	15,112	38,314
Najran	85,350	8,090	23,776	1,156	6,786	12,308	33,234
Jouf	70,176	4,926	20,670	1,437	4,451	23,328	15,364
TOTAL	**4,652,162**	**271,611**	**1,911,248**	**63,517**	**362,451**	**824,505**	**1,218,830**

5.4.2 Average household size

The average household size is the non-institutional population divided by the number of private households. The average household size in the country was 5.6 persons per household in 2010 [10] (see Table 5 - 14), a decrease from 5.8 in 1992.

Table 5 - 14 KSA, average household size by region in 2010

Administrative region	Average household size 2010	Average household size 2004	Average household size 1992
Riyadh	5.6	5.5	6.0
Makkah	5.0	4.8	5.3
Madinah	5.5	5.4	5.3
Qaseem	5.8	5.9	6.1
Eastern Region	6.1	5.9	6.4
Aseer	5.6	5.8	5.9
Tabouk	5.8	5.7	5.9
Hail	6.3	6.6	6.1
Northern Borders	7.3	7.2	7.6
Jazan	6.6	6.5	6.1
Najran	5.8	5.9	6.0
Baha	5.4	5.7	5.9
Jouf	6.1	7.2	6.7
National	5.6	5.5	5.8

Note: The number of occupants measures the average household size.

[10] Non-Institutional population divided by the number of households.

5.4.3 Household forecast

Neither CDSI nor the UN provides a household forecast. As shown earlier in Figure 9, the household can be derived from the population forecast by projecting the number of persons per household based on historical trends and assumed changes in the number of persons per household over the forecast period.

In the absence of any other study done by CDSI or further study prepared by any KSA Department or the UN, the following approach could be used if required:

1. If available, prepare a projection of the average number of persons per household (Saudi and non-Saudi) using data from past census and other estimates for specific years.
2. Extrapolate using a trend line projection and divide the population forecast for each scenario by this projection of the number of persons per household.
3. Check that the change in fertility rate ties into and produces the number of persons per household.

5.5 Water Demand Forecast Model

Water demand forecasting reaches future forecasts based on historical data (Billings and R. Bruce, 2008). Some of the questions that may be answered are:

- Will there be a need for more supply and storage? If yes, then how much more?
- Are the existing treatment plants sufficient?
- What is the plan for future demand changes, and how will they be met?

Several estimation methods are used to determine future demand, including analysis of historical data and linking that data with social and economic variables (Billings and R. Bruce, 2008). Models can be simple or complex depending on the variables used in that estimation.

One of the most common methods of calculating future water demand is the per capita consumption and multiplying it by the predicted future population (Billings and R. Bruce, 2008). This method is used in KSA but does not factor in changes in technology or consumption trends.

A more complex method of calculation will consider several variables. These variables include and are not limited to GDP, water prices, climate customer behaviour and regulations (Billings and R. Bruce, 2008). However, these models depend highly on the accuracy and availability of all the data beforehand, such as:

- Data requirements: water metering data (last 5 to 10 years) and historical water demand trends are subdivided into components (production, transmission, distribution).
- Adequacy of existing supplies stating that water demand in the past has been adequately met to allow interpreting water consumption data as water demand data:
- Water availability and adequate service levels regarding coverage, leakage, pressure, reliability, frequency of interruptions (24/7), etc.

- Diversity of the customer base: current water demand is split as far as possible into components (domestic, commercial, public utilities, and industrial).
- Economic data on household income per region.

The data obtained from various sources such as MoWE, NWC, SWCC, and published literature are insufficient to develop a detailed mathematical model for forecasting water demand. So, practical approaches for long-term water-demand forecasting: (1) per capita water-demand forecasts and (2) sectoral or per customer water-demand forecasts, disaggregated by major sectors such as residential, commercial, and industrial. These forecast approaches are utilized primarily to inform the design and acquisition of water system capacity. The focus is on annual usage.

Forecast horizons extend out one to several decades. Both approaches are simple in conception, although not necessarily in execution. Water demand for a system (customer group) is projected as the product of per capita water use (or unit-use coefficient for that customer group) multiplied by the population (number of customers in that group).

5.5.1 Factors affecting water demand

Increasingly complex constraints in source water availability, financial capacity, and concerns about climate change and other emerging uncertainties have led to more emphasis on evaluating, understanding, and modelling the factors that influence water use over short and long terms, such as:

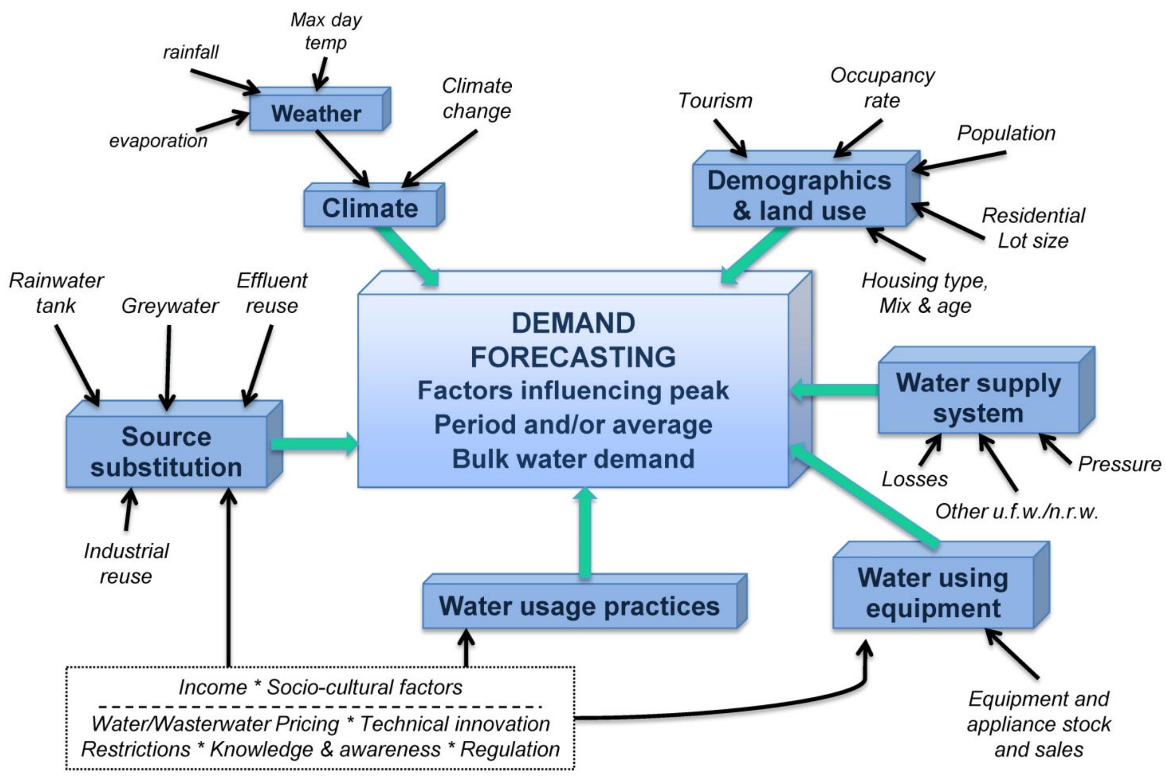
For short-term forecast:

- Restrictions on outdoor use due to water shortage.
- Economic/business cycles (such as recessions).
- New connections or the loss of a particular customer that is a large water user, for example, a factory shuts down).

Over longer time horizons, several factors can influence demand, including trends in:

- Population profile (Saudi, non-Saudi, age, etc.).
- Urban development (new cities, housing standing, density, and land use).
- Industrial cities and industrial units are located within the urban area.
- Disposable incomes and economic output.
- Price of water and sewer service.
- Water efficiency and conservation programs.
- Climate change and variability.

Figure 5 - 13, reprinted from the Water Services Association of Australia (WSAA), illustrates several direct and indirect factors influencing water demand and demand forecasting.



Source: Original Figure from Water Services Association of Australia Occasional Paper No. 9 – Urban Water Demand Forecasting and Demand Management.

Figure 5 - 13 Factors influencing water demand

5.5.2 Water demand approach

The development of the water demand forecast model requires the collection of various types of data:

- Baseline and forecast data at the national level, including:
- Population data,
- GDP data,
- Employment data,
- Water price data,
- Building data,
- Appliance data.
- Climate data

This data is then used to develop the water consumption model and sectorial demand forecast.

5.5.3 Main assumptions

The water consumption model is developed by estimating water consumption for different segments of users.

The main assumptions made during the development of the model are the following:

- Municipal water users have been classified into two categories: residential and non-residential. The model category considers various water-use segments to build the total consumption. On the other hand, as end-use discrimination is not viable for non-residential users, the consumption model developed has been simplified by considering the unitary consumption of an independent variable that properly describes the user type. The value of the unitary consumption will be obtained from the benchmark and actual public consumption.

- Residential and Non-residential customer categories have been selected based on the categories found in the available data and previous international experiences.

- Each segment's actual number of users will be needed during the extrapolation process. There is a high probability that this number cannot be directly obtained from the different sources' information, and it has to be somehow estimated. Therefore, the total national consumption figure will also be subject to this estimation error. This source of uncertainty will still be present.

- Water consumption predictions are on an average daily or yearly time frame. The model is not designed to predict specific users' weekly/hourly water consumption. It is only designed to predict average water consumption over time, making average values valid. However, if required, the model's structure could be modified to predict short-term water consumption (provided an appropriate analysis of short-term influencing variables is conducted). For this same reason, when exploring an independent variable's effect, each variable is only analyzed on average yearly terms. To illustrate this concept, take, for example, the independent variable: rainfall. The model will only consider the influence of the average rainfall throughout the year but not the effect on water consumption exerted by each rainfall event.

- The model will not provide values for the networks' daily peak water flow rate.

- The model has been developed to have the capability to calculate total water consumption at different levels, such as segments, categories, cities, the governorate level, and the regional level. It will work with one region as a sample for the model for simplifying purposes, limited time, and shortage of available data. However, some data sources required for the analysis will only be available at the national or regional level. In these cases, it will be necessary to conduct an analysis exercise to assign a correct value of the Temporal extrapolation and predictions of independent variables assumed to follow population or GDP values. No other parameter has been considered to drive future values of the independent variables used in the mode.

- Residential water consumption figures in the analysis are obtained in per capita terms. Total consumption is then calculated by multiplying per capita consumption by the number of household persons. However, it is estimated that the number of people living in a house by dividing the total population by the total number of houses is a parameter challenging to define and obtain in practice. A big effort has been made to calculate reliable per capita consumption figures from the consumption values obtained from the benchmark and actual public consumption.

5.5.4 Data source and assumption

Information on the population, commercial, and government is crucial to obtaining an accurate water demand forecast. As a general assumption, water demand requirements are associated with per capita water consumption for residential use and per unitary water consumption for non-residential use. However, a total count of the number of units of each water consumer category is needed. This is true not only at present but also for a year's projection, and therefore forecasts of population and building stock are an integral building block of the forecast.

5.5.5 Climatological data

The effect of climatological data on water consumption has been a frequently discussed research topic. Climatologic variables may have a short-term effect on water consumption, such as the outdoor cleaning of villas after a sandstorm. However, when estimating water consumption yearly, the effect of climatological variables on annual consumption is mainly associated with average (monthly/yearly) values and not so much with the changing daily variables. Therefore, climatological data is only helpful in monthly and annual terms to build a long-term water demand forecasting model.

Furthermore, climatological drivers are expected to mainly impact residential use; however, most non-residential activities will not be significantly affected. If they are, the effect will only be in the short term.

The data needed to build a long-term forecast can be accessible from sources like the General Authority of Meteorology and Environmental Protection, the General Authority of Meteorology and Environment Protection, the Jeddah Regional Climate Center, Climate-data, Climate Change Knowledge Portal, Department of Meteorology - Weather Forecasts from King Abdulaziz University.

5.5.6 Methodology

Water demand forecasts are usually developed in two phases, as Figure 5 - 14 shows in simplified terms (Billings and R. Bruce, 2008). In the first phase, analysts use rates based on rate levels. This produces a reference water demand forecast, which is usually the "unconstrained forecast" and is a direct analysis of current circumstances in the water system.

The second phase is derived from the reference estimate. The individual running the model can adjust the model to accommodate specific changes like water conservation. This adjustment will consider the prices ultimately in addition to other parameters. When this step is complete, it is regarded as a benchmark and only then can developments be reached with great impact.

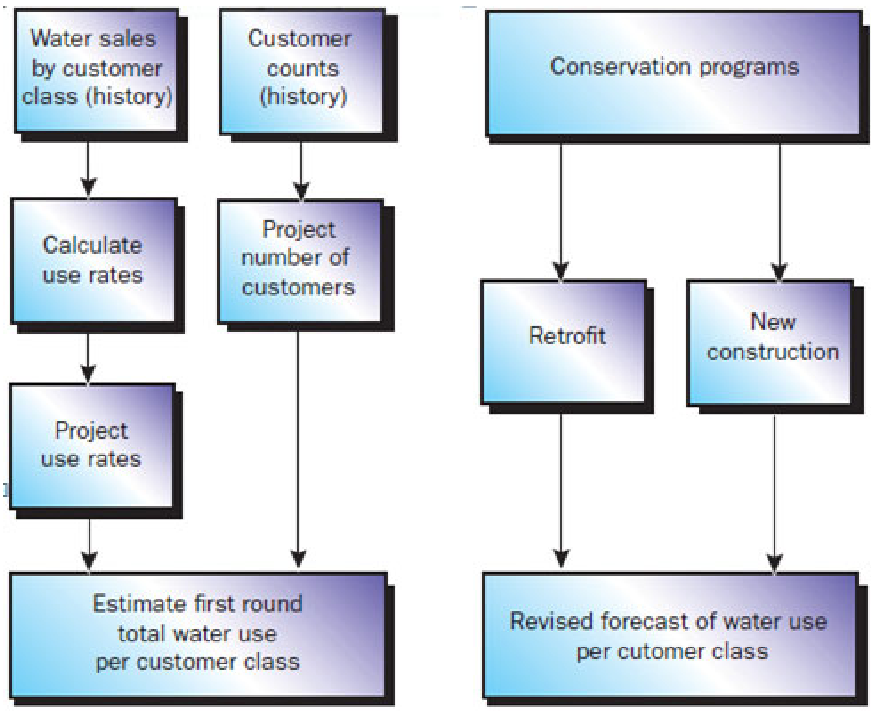


Figure 5 - 14 Simplified flow of work diagram for sectoral water-demand forecast

The research will focus on the first stage of water-demand forecasts.

5.6 Municipal Water Demand Forecast in KSA

Municipal water demand forecast has been based on an improved per capita (or a unitary rate of consumption) approach, where they have been identified according to regional and international benchmarking. Considering municipal water consumption disaggregated into two categories: residential and non-residential. These forecast approaches are utilized primarily to inform the design and acquisition of water system capacity. The focus is on annual usage. Forecast horizons extend out one to several decades. Water demand for a system (segment) is projected as the product of a per capita water use (or unit-use coefficient for that segment) multiplied by the population (number of customers in that segment), the growth rate of the segment, or GDP.

To avoid redundancy, it will be done in one region in KSA and then rolled out to the rest of the country.

Criteria for selecting the region:

- Population of that region
- Categories in that region to cover all consumption
- Climate of that region Saudi has different temperatures and spans many geographic topographies
- Social behaviours from area to area vary
- Supply sources where in some regions, they are more abundant than others
- Supply conditions

Based on the previous criteria, the Riyadh region was selected.

5.6.1 Riyadh region

Riyadh is the capital of the Kingdom of Saudi Arabia. It is in the middle of the Arabian Peninsula and is the 2nd largest populated region, following Makkah. Riyadh comprises a mix of Saudi citizens and expatriates and has a population of 8 million. The annual growth rate of the population is at 2% (Royal Commission for Riyadh, 2016).

The residential water consumption was estimated to be 308 L/capita/day according to (MOWE 2013). Riyadh receives 48% of its supply from underground treated water, while the other 52% is received via desalination plants on the east coast. Due to leaks in the system, the region loses about 22% of its supply (MEWA 2016).

Water is underpriced in KSA due to the government subsidy, which raises demand. Water consumption is partially metered, while leakage and water consumption per consumer (domestic, industrial, commercial, and government) are roughly estimated. Moreover, existing water supply statistics should not be considered for water demand trends. So, existing data are insufficient to develop curve fitting or regression techniques. Data quality needs to be improved to reach accurate future estimates.

5.6.1.1 Residential water demand forecast

Several factors that may affect per capita consumption need to be explored for residential water consumption. These factors must affect the short-term and long-term annual demand. Another important consideration is how difficult it is to obtain an accurate driver of consumption across the entire Kingdom. For this reason, a model is built as simply as possible and includes only those drivers of water demand that can be acquired at a national level and/or from reliable sources.

The following parameters were identified as the main drivers of residential water consumption:

- Family composition
- Origin of the family
- Number of housing units
- Region

The national expansion may lead to different drivers than those obtained during the development of this model.

Statistics about the different groups (segments) throughout the country must be obtained from the most recent Population and Housing Census from the General Authority for Statistics (STATS) conducted in 2016. Once water consumption drivers have been identified, this information will allow for the stratification of residential customers into various categories.

In urban areas with high socioeconomic standing, the average water demand of 200 L/capita/day is expected to be maintained. In contrast, in rural areas and small cities under 100,000 persons, the water demand is likely below 156 L/capita/day, corresponding to 100 L/capita/day as net residential consumption recommended by Water Health Organization as an optimum water allocation (WHO 2003). While in 2013, the national water strategy (NWS) targeted 170 L/capita/day for municipal water demand.

In 2014, Abu Dhabi developed an end-user study of residential water demand where the study's outcome was that the average per capita water consumption was 168 L/capita/day (Abu Dhabi Bureau, 2014).

The MoWE municipal water demand forecast is based on supply-side management with a fixed per capita approach. Each city's per capita water allocation is set according to its size, depending on its population. For example, 250 L/capita/day is set for cities with more than 85,000 people, 200 L/capita/day for cities between 5,000 and 85,000 people, and 150 L/capita/day for cities with less than 5,000 people. This approach assumes that the water supply is proportional to population growth and that per capita water use will not change.

5.6.1.1.1 Residential water consumption module selection and calculation

The residential water consumption module's selection will depend on equations based on available parameters from two approaches. First, daily residential water consumption equations are based on the number of houses with household members and per capita when irrigation or outdoor area is known. Second, daily residential water consumption equations are based on the number of houses with household members and per capita when irrigation or outdoor area is unknown. These approaches, with their parameters, need to be filtered to estimate total residential water consumption.

Unfortunately, when irrigation or outdoor area is unknown, daily residential water consumption equations based on the number of houses with household members and per capita cannot be selected to calculate total water consumption. So, this approach will be neglected.

In 2016, the General Authority for Statistics published a demography survey for all regions in KSA. The outcome was about the total number of housing units with household members determined for different housing units in the Riyadh region for Saudis and Non-Saudis. So, different relations and calculations can be obtained to define the household members in a housing unit, as shown in Table 5 - 15.

Table 5 - 15 Summarized residential statistics information and calculation obtained in Riyadh region in 2016

HOUSING UNIT TYPE		Total	Other	Apartment	Floor in Traditional House	Floor in Villa	Villa	Traditional House
Saudi	Housing Units	809437	711	222213	4755	144498	384111	53149
	Households occupants	5126104	1213	979050	28536	885578	2938256	293471
	Households occupants in housing unit	**6**	**2**	**4**	**6**	**6**	**8**	**6**
Non-Saudi	Housing Units	32356	980	10658	1237	560	569	18352
	Households occupants	32356	980	10658	1237	560	569	18352
	Households occupants in housing unit	**4**	**1**	**5**	**4**	**7**	**8**	**4**

(Source: Demography Survey 2016 _General Authority for Statistics).

Daily residential water consumption equations based on the number of houses with household occupants and per capita can be selected and calculated when the irrigation area is unknown.

Therefore, total residential water consumption in KSA can be obtained based on the assumption that the per capita water consumption is 170 L/capita/day (NWS 2013) and the parameters, as expressed in Table 5 - 15. These parameters are applied in daily residential water consumption equations according to the number of household occupants and per capita when the irrigation area is unknown, with the hypothesis that irrigation or outdoor water consumption is applied to villa housing type only, as summarized in Table 5 - 16.

Table 5 - 16 Residential water consumption equations selection and calculation in 2016

Nationality	Housing unit type	Households occupants in housing unit	Total water consumption in housing unit L/day
Saudi	**Other**	**Two households' occupants in housing unit**	
	Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with two occupants and Per Capita water consumption when the Irrigation Area (IA) is unknown. $TRWC_2 = Per\ Cap.\cdot NH_2\cdot((1 + C_2). + C_{IOA-2})$		181465
	Apartment	**Four household occupants in housing unit**	
	Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with four occupants and Per Capita water consumption when the Irrigation Area (IA) is unknown. $TRWC_4 = Per\ Cap.\cdot NH_4\cdot((1 + C_4). + C_{IOA-4})$		119835720
	Floor in Traditional House	**Six household occupants in housing unit**	
	Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with six and more occupants and Per Capita water consumption when the Irrigation Area (IA) is unknown. $TRWC_6 = Per\ Cap.\cdot NH_6\cdot((1 + C_6). + C_{IOA-6})$		2862161
	Floor in Villa	**Six household occupants in housing unit**	
	Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with six and more occupants and Per Capita water consumption when the Irrigation Area (IA) is unknown. $TRWC_6 = Per\ Cap.\cdot NH_6\cdot((1 + C_6). + C_{IOA-6})$		88823473
	Villa	**Eight household occupants in housing unit**	
	Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with six and more occupants and Per Capita water consumption when the Irrigation Area (IA) is unknown. $TRWC_8 = Per\ Cap.\cdot NH_8\cdot((1 + C_8). + C_{IOA-8})$		312,244,262
	Traditional House	**Six household occupants in housing unit**	
	Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with six and more occupants and Per Capita water consumption when the Irrigation Area (IA) is unknown. $TRWC_6 = Per\ Cap.\cdot NH_6\cdot((1 + C_6). + C_{IOA-6})$		29435141

<table>
<tr><td rowspan="18">Non- Saudi</td><td>Other</td><td>One household occupant in housing unit</td><td rowspan="2">172890</td></tr>
<tr><td colspan="2">Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with one occupant and Per Capita water consumption when Irrigation Area (IA) is unknown.

$TRWC_1 = Per\ Cap.\cdot NH_1\cdot((1 + C_1). + C_{IOA-1})$</td></tr>
<tr><td>Apartment</td><td>Five household occupants in housing unit</td><td rowspan="2">5942911</td></tr>
<tr><td colspan="2">Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with five occupants and Per Capita water consumption when the Irrigation Area (IA) is unknown.

$TRWC_5 = Per\ Cap.\cdot NH_5\cdot((1 + C_5). + C_{IOA-5})$</td></tr>
<tr><td>Floor in Traditional House</td><td>Four household occupants in housing unit</td><td rowspan="2">552514</td></tr>
<tr><td colspan="2">Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with four occupants and Per Capita water consumption when the Irrigation Area (IA) is unknown.

$TRWC_4 = Per\ Cap.\cdot NH_4\cdot((1 + C_4). + C_{IOA-4})$</td></tr>
<tr><td>Floor in Villa</td><td>Seven household occupants in housing unit</td><td rowspan="2">368001</td></tr>
<tr><td colspan="2">Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with six and more occupants and Per Capita water consumption when the Irrigation Area (IA) is unknown.

$TRWC_7 = Per\ Cap.\cdot NH_7\cdot((1 + C_7). + C_{IOA-7})$</td></tr>
<tr><td>Villa</td><td>Eight household occupants in housing unit</td><td rowspan="2">463,225</td></tr>
<tr><td colspan="2">Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with six and more occupants and Per Capita water consumption when the Irrigation Area (IA) is unknown.

$TRWC_8 = Per\ Cap.\cdot NH_8\cdot((1 + C_8). + C_{IOA-8})$</td></tr>
<tr><td>Traditional House</td><td>Four household occupants in housing unit</td><td rowspan="2">8322710</td></tr>
<tr><td colspan="2">Total Residential Water Consumption (TRWC) based on the Number of Houses (NH) with four occupants and Per Capita water consumption when the Irrigation Area (IA) is unknown.

$TRWC_4 = Per\ Cap.\cdot NH_4\cdot((1 + C_4). + C_{IOA-4})$</td></tr>
<tr><td colspan="3">Total Residential Water Consumption L/day</td><td>569,204,473</td></tr>
</table>

In 2016, the Riyadh region's total residential water consumption estimation for Saudis and Non-Saudis was 569,204,473 L/day. This total was determined by multiplying the average ratio of per capita water consumption based on the number of household occupants with the per capita water consumption as the national water strategy target of 170 L/capita/day (NWS 2013) by the total number of housing units based on different types of housing unit (STATS 2016). Also, multiplying the water consumption ratio in irrigation or outdoor area based on the number of household members with the per capita water consumption as the national water strategy target of 170 L/capita/day (NWS, 2013) by the total number of housing unit based on different types of house unit which is restricted only to villa based on the hypothesis.

5.6.1.2 Non-residential water demand forecast

While total residential water consumption can be estimated using several average per capita consumption figures for the different types of residential users, non-residential users are significantly more difficult to describe. Each non-residential water consumption customer category has a different "unit" or main driver describing water consumption.

The actual weight of each category must be determined depending on the number of units and the consumption associated with each unit. These are the likely best proxies available for water consumption.

The forecast in unit water consumption can be done in different ways depending on the subsector involved:

1. Based on the population change: healthcare, education, and mosques all depend on the number of people they serve.
2. Based on the change in **GDP**: commercial sectors such as hospitality, restaurants, and retail depend on money people can spend. Ideally, "household disposable income" would be used, but only the current GDP forecast is available.

5.6.1.2.1 Non-Residential water consumption module selection and calculation

The selection of non-residential water consumption modules will depend on selecting equations based on available parameters for each customer category based on available parameters. So, these approaches' parameters must be filtered to estimate total non-residential water consumption.

5.6.1.2.1.1 Hotel water consumption module selection and calculation

The selection of the hotel water consumption module will depend on the selection of the equations used. In turn, they will be based on the available parameters: floor area (FA), number of guests (NG), number of guests (NG) with cooling and heating area (CHA), irrigation area (IA) and number of rooms (NR) and number of rooms (NR) with cooling and heating area (CHA) and irrigation area (IA). So, these parameters need to be filtered to obtain a unitary water consumption as the following:

- Floor Area (FA); the hotel's floor area can be selected as a parameter to estimate hotel water consumption. Unfortunately, the Ministry of Municipal and Rural Affairs (MoMRA), Ministry of Commercial and Investment (MoCI), and Tourism Information and Research Center Establishment Statistics did not publish this parameter. These numbers can be found in hotel construction licenses in the Riyadh region but were unavailable when developing the thesis. So, this parameter is ignored.

- Number of Guests (NG); the number of guests can be selected as a parameter to estimate hotel water consumption. It is expected to correlate best with the hotel's actual water consumption and is mainly related to the number of staff. But cannot be selected as a parameter. Because these numbers are unfortunately not available when developing the thesis. They can also be changed occasionally in the same hotel and not accounted for with the empty hotels. So, this parameter can be ignored.

- The Number of Guests (NG) in the cooling and heating area (CHA) and irrigation area (IA) can be selected as a parameter to estimate hotel water consumption. It is expected to correlate best with the actual water consumption and would be mostly related to the number of staff (in their washrooms consumption). But the cooling and heating area (CHA) and irrigation area (IA) were not published by the Ministry of Municipal and Rural Affairs (MoMRA) and Ministry of Commercial and Investment (MoCI). Despite these, numbers can be found in some hotels but not all Riyadh region hotels. So, we can ignore this parameter.

- Number of Rooms (NR); the hotel's number of rooms is selected as a parameter to estimate its water consumption. It is expected to correlate best with the hotel's actual water consumption, and it would be mostly related to the number of staff (in their consumption in washrooms). However, these numbers can be found in the Research Centre Establishment Statistics.

- The Number of rooms (NR) with cooling and heating area (CHA) and irrigation area (IA) in the hotel can be selected as a parameter to estimate hotel water consumption. It is expected to correlate best with the actual water consumption and would be mostly related to the number of staff (in their washrooms consumption). But the cooling and heating area (CHA) and irrigation area (IA) were not published by the Ministry of Municipal and Rural Affairs (MoMRA) and Ministry of Commercial and Investment (MoCI). Despite these numbers can be found in some of the hotels but not for all Riyadh region hotels. So, we can ignore this parameter.

As a result, daily hotel water consumption equations based on the number of rooms (NR) are selected.

$$TWC_{hotel} = NR \cdot (C_{NR} + C_{CHA,U} \cdot (1/R_{CHA,U}^{NR}) + C_{IA,U} \cdot (1/R_{IA,U}^{NR}))$$

In 2016, Information and Research Center Establishment Statistics (MAS, 2016) published statistics about the total number of rooms in hotels in the Riyadh region as 11,534 rooms. The hotel's growth rate in 2016 was 6.6% (Saudi Arabian Monetary Agency, 2015). Also, from the analysis, the rest of the parameters as expressed in Table 4 - 13.

Thus, the amount of hotel water consumption can be calculated as 11,105,594 L/day for 2016 in the Riyadh region.

5.6.1.2.1.2 Restaurants water consumption module and calculation

The selection of the restaurant water consumption module will depend on the selection of equations used. In turn, these will be based on the available parameters: floor area (FA), number of customers (NC), number of customers (NC) with cooling and heating area (CHA), irrigation area (IA), number of employees (NE), number of employees (NE) with cooling and heating area (CHA) and irrigation area (IA), number of seats (NS), number of seats (NS) with cooling and heating area (CHA) and irrigation area (IA), number of meals and number of meals (NM) with cooling and heating area (CHA) and irrigation area (IA). So, these parameters need to be filtered to obtain a unitary water consumption as the following:

- Floor Area (FA); the restaurants' floor area can be selected as a parameter to estimate restaurants' water consumption. Unfortunately, the Ministry of Municipal and Rural Affairs (MoMRA), Ministry of Commercial and Investment (MoCI), and Tourism Information and Research Center Establishment Statistics did not publish this parameter. These numbers can be found in restaurant construction licenses in the Riyadh region but were unavailable when developing the thesis. So, this parameter is ignored.

- Number of Employees (NE); the number of employees is selected as a parameter to estimate restaurants' water consumption. Therefore, it is expected to correlate best with the actual number of customers and is used. Even though these numbers can be found in different sources (Ministry of Label (MoL), Royal Commission for Riyadh City (RCRC) or Central Department of Statistics and Information (CDSI)), each one of them gives the number of employments or the number of employments in food and beverage sector without specifying the restaurant employment share. The only source for defining this number is Tourism Information and Research Center Establishment Statistics (MAS, 2013).

- Number of Employees (NE) with cooling and heating area (CHA) and irrigation area (IA) to estimate restaurants' water consumption. It is expected to correlate best with the actual number of customers. But the cooling and heating area (CHA) and irrigation area (IA) were not published by the Ministry of Municipal and Rural Affairs (MoMRA) and Ministry of Commercial and Investment (MoCI). Despite these numbers can be found in some of the restaurants but not for all Riyadh region restaurants. So, we can ignore this parameter.

- Number of Customers (NC); the number of restaurant customers can be selected as a parameter. It is defined in Tourism Information and Research Centre Establishment Statistics (MAS, 2013) but does not account for empty restaurants. So, this parameter is ignored.

- Number of Seats (NS) and Number of Meals (NM) can be selected to estimate restaurants' water consumption. Unfortunately, these numbers are not available when developing the model. Also, these numbers can be changed occasionally in the same restaurant and don’t account for empty restaurants. So, this parameter is ignored.

As a result, daily restaurant water consumption equations based on the number of employees (NE) are selected.

$$TWC_{restaurant} = NE \cdot (C_{NE} + C_{CHA,U} \cdot (1/R^{NE}_{CHA,U}) + \ C_{IA,U} \cdot (1/R^{NE}_{IA,U}))$$

In 2013, Tourism Information and Research Center (MAS, 2013) published statistics about the total number of employees in food and beverage services in the Riyadh region as 106,106 employees. Also, it determined the restaurants' employees share around 90%. This meant that the number of restaurant employees in the Riyadh region could be calculated to be 95,580 employees.

In 2014, the restaurants' growth rate was 6.6% (MAS, 2013, the Saudi Arabian Monetary Agency, 2015). This meant that the estimated number of employees was 115,781 employees in 2016. So, the water consumption in restaurants can be calculated as 52,400,445 L/day for 2016 in the Riyadh region.

5.6.1.2.1.3 Cafe water consumption module selection and calculation

The selection of cafe water consumption module will depend on the selection of equations used based on available parameters, which are floor area (FA), number of employees (NE), number of employees (NE) with cooling and heating area (CHA) and irrigation area (IA), number of seats (NS) and number of seats (NS) with cooling and heating area (CHA) and irrigation area (IA). So, these parameters need to be filtered to obtain a unitary water consumption as the following:

- Floor area (FA); the cafes' floor area can be selected as a parameter to estimate cafes' water consumption. Unfortunately, the Ministry of Municipal and Rural Affairs (MoMRA), Ministry of Commercial and Investment (MoCI), and Tourism Information and Research Center Establishment Statistics did not publish this parameter. These numbers can be found in cafe construction licenses in the Riyadh region but are unavailable when developing the thesis. So, this parameter is ignored.

- Number of Employees (NE); the number of employees is selected as a parameter to estimate cafes' water consumption. Therefore, it is expected to correlate best with the actual number of customers and is used. Even though these numbers can be found in different sources (Ministry of Label (MoL), Royal Commission for Riyadh City (RCRC), and Central Department of Statistics and Information (CDSI)), each one of them gives the number of employments or the number of employments in food and beverage sector without specifying the cafe employees share. The only source for defining this number is Tourism Information and Research Center Establishment Statistics (MAS, 2013).

- Number of Employees (NE) with cooling and heating area (CHA) and irrigation area (IA) to estimate cafes' water consumption. It is expected to correlate best with the actual number of customers. However, the cooling and heating area (CHA) and irrigation area (IA) was not published by the Ministry of Municipal and Rural Affairs (MoMRA) and Ministry of Commercial and Investment (MoCI). Despite these numbers can be found in some of the cafes but not for all Riyadh region cafes. So, we can ignore this parameter.

- Number of Seats (NS); the number of seats can be selected as a parameter to estimate restaurants' water consumption. Unfortunately, these numbers are not available when developing the model. Also, these numbers can be changed occasionally in the same restaurant and don’t account for empty restaurants. So, this parameter is ignored.

As a result, daily cafe water consumption equations based on the number of employees (NE) are selected.

Total Water Consumption (TWC) in the cafe based on Number of Employees (NE) when Cooling and Heating area (CHA) and Irrigation Area (IA) are unknown.

$$TWC_{cafe} = NE \cdot (C_{NE} + C_{CHA,U} \cdot (1/R^{NE}_{CHA,U}) + C_{IA,U} \cdot (1/R^{NE}_{IA,U}))$$

In 2013, Tourism Information and Research Center (MAS, 2013) published statistics about the total number of employees in food and beverage services in the Riyadh region as 106,106 employees. Also, it determined the cafes' employees share as around 10%. This meant that the number of cafes employees in the Riyadh region could be calculated to be 10611 employees.

In 2014, the cafes' growth rate was 6.6% (MAS, 2013, the Saudi Arabian Monetary Agency, 2015). This meant that the estimated number of employees was 12,853 employees in 2016. The rest of the parameters are expressed in Table 4 - 48 and Table 4 - 49.

So, the amount of water consumption in cafes can be calculated as 34,493,415 L/day for 2016 in the Riyadh region.

5.6.1.2.1.4 Office water consumption module selection and calculation

The selection of the office water consumption module will depend on the selection of equations used based on available parameters, which are the number of employees (NE), number of employees (NE) with cooling and heating area (CHA) and irrigation area (IA) and floor area (FA). Therefore, these parameters need to be filtered to obtain a unitary water consumption as the following:

- Floor area (FA); the offices' floor area can be selected as a parameter to estimate offices' water consumption. Unfortunately, the Ministry of Municipal and Rural Affairs (MoMRA), Ministry of Commercial and Investment (MoCI), and Tourism Information and Research Center Establishment Statistics did not publish this parameter. These numbers can be found in office construction licenses in the Riyadh region but are unavailable when developing the thesis. So, this parameter is ignored.

- Number of Employees (NE); the number of employees can be selected as a parameter to estimate offices' water consumption. It is expected to correlate best with the actual water consumption in toilets. Even though these numbers can be found in different sources (Ministry of Label (MoL), Royal Commission for Riyadh City (RCRC), and Central Department of Statistics and Information (CDSI)), each one of them gives the total number of employments or the total number of employments in the commercial sector without specifying offices employees share. So, this parameter is ignored.

- Number of Employees (NE) with cooling and heating area (CHA) and irrigation area (IA) to estimate offices' water consumption. It is expected to correlate best with the actual water consumption in toilets. But the cooling and heating area (CHA) and irrigation area (IA) were not published by the Ministry of Municipal and Rural Affairs (MoMRA) and Ministry of Commercial and Investment (MoCI). Despite these numbers can be found in some of the offices but not for all Riyadh region offices. So, we can ignore this parameter.

- Since the floor area and the number of employees are not published and available in published sources at the time of developing the thesis—the best way to obtain one of these parameters is through estimations. The floor area parameter is found (confidential source) where they estimate the floor area of the offices for the main region (Central, East, South, West). Then this estimation can be linked and allocated to an administrative region based on population to determine the number for the Riyadh region.

As a result, daily office water consumption equations based on the floor area (FA) are selected.

Total Water Consumption (TWC) in the office based on Floor Area (FA) in square meters when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known.

$$TWC_{\text{office}} = FA \cdot (C_{FA} + C_{CHA,U} + C_{IA,U})$$

In 2016, the floor area parameter was found (confidential source), where they estimated the floor area of the offices for the main region (Central, East, South, and West). Then this estimation can be linked and allocated to an administrative region based on population to determine the floor area for the Riyadh region as 41,748,000 m^2. The rest of the parameters are expressed in Table 4 - 63.

The growth rate for an office building is based on GDP growth of 0.9% in 2017 (Saudi Arabian Monetary Agency, 2015).

So, the amount of water consumption in the office building can be calculated as 121,116,200 L/day for 2016 in the Riyadh region.

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5.6.1.2.1.5 Wholesale and retail water consumption module selection and calculation

The selection of wholesale and retail water consumption module will depend on the selection of equations used based on available parameters, which are floor area (FA), number of employees (NE) and number of employees (NE) with cooling and heating area (CHA) and irrigation area (IA). So, these parameters need to be filtered to obtain a unitary water consumption as the following:

- Floor area (FA); the wholesale and retail floor area can be selected as a parameter to estimate wholesale and retail' water consumption. Unfortunately, the Ministry of Municipal and Rural Affairs (MoMRA) and the Ministry of Commercial and Investment (MoCI) did not publish this parameter. These numbers can be found in office construction licenses in the Riyadh region but are unavailable when developing the thesis. So, this parameter is ignored.

- Number of employees (NE); the number of employees is selected as a parameter to estimate wholesale and retail water consumption. It is expected to correlate best with the actual water consumption in toilets.

- Number of employees (NE) with cooling and heating area (CHA) and irrigation area (IA) to estimate wholesale and retail water consumption. It is expected to correlate best with the actual water consumption in toilets. But the cooling and heating area (CHA) and irrigation area (IA) were not published by the Ministry of Municipal and Rural Affairs (MoMRA) and Ministry of Commercial and Investment (MoCI). Despite these numbers, it can be found in some wholesale and retail but not for all Riyadh region cafes. So, this parameter is ignored.

As a result, daily wholesale and retail trade water consumption equations are based on the number of employees (NE).

Total Water Consumption (TWC) in the wholesale and retail trade based on Number of Employees (NE) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are unknown.

$$TWC_{wholesale\ and\ retail\ trad} = NE{\cdot}(C_{NE} + C_{CHA,U}{\cdot}(1/R_{CHA,U}^{NE}) + C_{IA,U}{\cdot}(1/R_{IA,U}^{NE}))$$

In 2016, the Central Department of Statistics and Information (CDSI 2016) published statistics about the total number of employees in wholesale and retail trades in the Riyadh region as 482,733 employees. The rest of the parameters are expressed in Table 4 - 70 and Table 4 - 71.

The growth rate for wholesale and retail trade is based on population growth of 3% in 2016 (Saudi Arabian Monetary Agency, 2016).

So, the amount of water consumption in wholesale and retail trade can be calculated as 237,760,303 L/day for 2016 in the Riyadh region.

5.6.1.2.1.6 School water consumption module selection and calculation

The selection of the school water consumption module will depend on the selection of equations used based on available parameters, which are floor area (FA), number of students (NS) and number of students (NS) with cooling and heating area (CHA) and irrigation area (IA). So, these parameters need to be filtered to obtain a unitary water consumption as the following:

- Floor area (FA); the elementary, secondary and high schools' floor area can be selected to estimate schools' water consumption. Unfortunately, the Ministry of Education (MoE) did not publish this parameter. These numbers can be found in school construction licenses in the Riyadh region but are unavailable when developing the thesis. So, this parameter is ignored.

- Number of students (NS); the number of students in elementary, secondary, and high school is selected as a parameter to estimate schools' water consumption. It is expected to correlate best with the actual water consumption in toilets. Even these numbers can be found in the Ministry of Education (MoE).

- Number of students (NS) with cooling and heating area (CHA) and irrigation area (IA) to estimate the elementary, secondary, and high schools' water consumption. It is expected to correlate best with the actual water consumption in toilets. But the cooling and heating area (CHA) and irrigation area (IA) were not published by the Ministry of Municipal and Rural Affairs (MoMRA) and the Ministry of Education (MoE). Despite these numbers can be found in some of the schools but not for all Riyadh region schools. So, this parameter is ignored.

As a result, daily elementary, secondary, and high school water consumption equations are selected based on the number of students (NS).

Total Water Consumption (TWC) in the elementary, secondary, high school and schools, in general, based on the Number of Students (NS), when Cooling and Heating area (CHA) and Irrigation area (IA) are unknown.

$$TWC_{schools} = NS \cdot (C_{NS} + C_{CHA,U} \cdot (1/R^{NS}_{CHA,U}) \ + \ C_{IA,U} \cdot (1/R^{NS}_{IA,U}))$$

In 2016, the ministry of education (MoE) published the number of elementary, secondary, and high school students in the Riyadh region as the following in sequence 886,179, 388,737, and 373,359. These numbers can be divided by the population in 2006, which is 800,2089 (CDSI 2016), to obtain the density in sequence as 0.111, 0.048, and 0.046 student/per capita. After that, this density multiplies by and extrapolate with the population. The rest of the parameters are expressed in Table 4 - 79 and Table 4 - 80.

The growth rate for elementary, secondary, and high schools is based on population growth of 3% in 2016 (Saudi Arabian Monetary Agency, 2016).

So, the amount of water consumption in elementary, secondary, and high school can be calculated in sequence as (126,993,249), (51,631,832) and (70,252,473) L/day for 2016 in the Riyadh region.

5.6.1.2.1.7 University water consumption module selection and calculation

The selection of the university water consumption module will depend on the selection of equations used based on available parameters, which are the per capita (PC), the per capita (PC) with cooling and heating area (CHA) and irrigation area (IA), the floor area (FA), the number of students (NS) and the number of students (NS) with cooling and heating area (CHA) and irrigation area (IA). So, these parameters need to be filtered to obtain a unitary water consumption as the following:

- The Per Capita (PC), which includes students, faculty, staff, and visitors, is expected to correlate best with the actual water consumption in the university. Unfortunately, the Ministry of Higher Education (MoHE) did not publish this parameter. Even though these numbers can be found in some individual universities, the overall Riyadh region is not available when developing the thesis. So, this parameter is ignored.

- The Per Capita (PC) with cooling and heating area (CHA) and irrigation area (IA), which include students, faculty, staff, visitors, cooling and heating area (CHA), and irrigation area. It is expected to correlate best with the actual water consumption in the university. Unfortunately, the Ministry of Higher Education (MoHE) did not publish this parameter. Even though these numbers can be found in some individual universities, in the Riyadh region, they are not available. So, this parameter is ignored.

- Floor area (FA), the universities' floor area cannot be selected as a parameter to estimate universities' water consumption in KSA because most university campuses in Saudi Arabia are a mix of student residential colleges, office buildings, hospitals, schools, sports complexes, faculty and student housing, and restaurants. So, this parameter is ignored.

- Number of Students (NS), the number of university students, can be selected as a proxy to correlate best with the actual water consumption in the university and is therefore used even though these numbers can be found in the Ministry of higher education (MoHE).

  Number of Students (NS) with cooling and heating area (CHA) and irrigation area (IA) to estimate universities' water consumption. It is expected to correlate best with the actual water consumption in the university. But the cooling and heating area (CHA) and irrigation area (IA) were not published by the Ministry of Municipal and Rural Affairs (MoMRA) and the Ministry of Education (MoE). Despite these numbers can be found in some of the universities but not for all Riyadh region universities. So, this parameter is ignored.

As a result, daily university water consumption equations are selected based on the number of students (NS).

Total Water Consumption (TWC) in the university-based Number of students (NS) when the Cooling and Heating area (CHA) and Irrigation area (IA) are unknown.

$$TWC_{university} = NS \cdot (C_{NS} + C_{CHA,U} \cdot (1/R_{CHA,U}^{NS}) + C_{IA,U} \cdot (1/R_{IA,U}^{NS}))$$

In 2014, the Ministry of Higher Education (MoHE) published the number of university students. The total number of students in the university was 396,470 students in the Riyadh region. The rest of the parameters are expressed in Table 4 - 93 and Table 4 -94.

The university's growth rate based on population growth was 3% in 2015 (Saudi Arabian Monetary Agency,2015).

So, the amount of water consumption in universities can be calculated as 58,915,442 L/day for 2016 in the Riyadh region.

5.6.1.2.1.8 Hospital water consumption module selection and calculation

The selection of the hospital water consumption module will depend on the selection of equations used based on available parameters, which are the per capita (PC), the per capita (PC) with cooling and heating area (CHA) and irrigation area (IA), the floor area (FA), the number of beds (NB) and the number of beds (NB) with cooling and heating area (CHA) and irrigation area (IA). So, these parameters need to be filtered to obtain a unitary water consumption as the following:

- The Per Capita (PC) includes patients, physicians, nurses, pharmacists, and allied health personnel. It is expected to correlate best with the actual water consumption in the hospital. Since it is mainly related to the facility used, the Ministry of Health (MoH) did not publish this parameter. Even though these numbers can be found in some individual hospitals, the Riyadh region is not available when developing the thesis. So, this parameter is ignored.

- The Per capita (PC) with Cooling and heating area (CHA) and irrigation area (IA) in the hospital, which includes patients, physicians, nurses, pharmacists, and allied health personnel, consider the cooling, heating and irrigation area. They are expected to correlate best with the actual water consumption in the hospital. Since it is mostly related to the facility used, the Ministry of Health (MoH) did not publish this parameter. Even though these numbers can be found in some individual hospitals in the Riyadh region, they were not available when developing the thesis. So, this parameter is ignored.

- Floor Area (FA); the hospitals' floor area can be selected as a parameter to estimate hospitals' water consumption. Unfortunately, the Ministry of Health (MoH) did not publish this parameter. These numbers can be found in hospital construction licenses in the Riyadh region but were unavailable when developing the thesis. So, this parameter is ignored.

- Number of Beds (NB); the number of hospital beds is selected as a parameter because it is expected to correlate best with the actual number of patients, physicians, nurses, pharmacists, and allied health personnel and the current water consumption in hospitals and is therefore used. Even these numbers can be found in the Ministry of Health (MoH).

- Number of Beds (NB) with the Cooling and heating area (CHA) and irrigation area (IA) to estimate hospitals' water consumption. It is expected to correlate best with the number of patients, physicians, nurses, pharmacists, allied health personnel, and hospital water consumption. But the cooling and heating area (CHA) and irrigation area (IA) were not published by the Ministry of Health (MoH). Despite these numbers can be found in some of the hospitals but not for all Riyadh region hospitals. So, this parameter is ignored.

As a result, daily hospital water consumption equations based on the number of beds (NB) are selected.

Total Water Consumption (TWC) in the hospital Number of Beds (NB) when Cooling and Heating Area (CHA) and Irrigation Area (IA) are known

$$TWC_{hospital} = NB \cdot (C_{NB} + C_{CHA,U} \cdot (1/R^{NB}_{CHA,U}) + C_{IA,U} \cdot (1/R^{NB}_{IA,U}))$$

In 2016, the Ministry of Health published a statistics report determining that the number of beds in the Riyadh region was 21,331 (Ministry of Health, 2016). This number was divided by the population in 2006, 800,2089 (CDSI 2016), to determine the density as 0.0026 (bed/capita). After that, this density multiplies by and extrapolate with the population. The rest of the parameters are expressed in Table 4 - 107 and Table 4 - 108.

The hospital's growth rate is based on a population growth of 3% in 2016 (Saudi Arabian Monetary Agency, 2016).

So, the amount of water consumption in hospitals can be calculated as 12,446,131 L/day for 2016 in the Riyadh region.

5.6.1.2.1.9 Mosque water consumption module selection and calculation

The selection of the mosque water consumption module will depend on the selection of equations used based on available parameters, which are the number of mosques (NM) with cooling and heating area (CHA) and irrigation area (IA) and the number of worshippers (NP) with cooling and heating area (CHA) and irrigation area (IA). So, these parameters need to be filtered to obtain a unitary water consumption as the following:

- Number of Mosques (NM) with cooling and heating area (CHA) and irrigation area (IA) in the mosques can be selected as a parameter to estimate hospitals' water consumption. It is expected to correlate best with the actual water consumption in the mosque. Water consumption in mosques would be mostly related to the number of visitors. As the number of worshippers is not available when developing the thesis and not published by the Ministry of Waqfs, Islamic Affairs, Dawa, and guidance (MoWIADG) alternative, the number of mosques is used together with the average water consumption of a mosque.

- Number of worshippers (NW) with cooling and heating area (CHA) and irrigation area (IA) to estimate mosques' water consumption. It is expected to correlate best with the actual water consumption in the mosque. Unfortunately, these numbers are not available when developing the model and are not published by the Ministry of Waqfs, Islamic Affairs, Dawa, and guidance (MoWIADG). These numbers can also be changed occasionally in the same restaurant and don't account for empty mosques.

As a result, daily mosque water consumption equations based on the number of mosques (NM) are selected.

Total Water Consumption (TWC) in the mosque based on the number of mosques (NM) when Cooling and Heating area (CHA) and Irrigation Area (IA) are unknown, and they cannot be estimated.

$$TWC_{mosque} = C_{NM,T} \cdot NM$$

In 2016, the Ministry of Waqfs, Islamic Affairs, Dawa, and guidance (MoWIADG) published a statistics report that determined that the number of mosques in the Riyadh region was 17,953 (MoWIADG 2016). This number is divided by the population in 2006, which was 800,208 per capita (CDSI 2016), to determine the density as 0.0022 (mosque/capita). After that, this density multiplies by and extrapolate with the population. The rest of the parameters are expressed in Table 4 - 111.

The mosque's growth rate is based on a population growth of 3% in 2016 (Saudi Arabian Monetary Agency, 2016).

So, the total water consumption in mosques can be calculated as 234,843,193 L/day for 2016 in the Riyadh region.

Chapter 6
CONCLUSION

6 CONCLUSION

6.1 General conclusion

The municipal water consumption model provides a wealth of information on how water is consumed throughout residential and non-residential. It will be the primary input to the new bottom-up forecast and future policy initiatives.

The municipal water consumption model provides a framework for the required data to be built on further. The model is designed to provide a forecast on any level. Still, currently, the available data and time limits allow the results to be differentiated only on an Administrative Region basis. This water consumption at the level of the one region example gives a granular view of the country's water demand.

Different rounds of review and feedback can be allowed to improve the model further, and it can be applied to supplement and challenge the top-down water demand forecasts.

The model focuses on non-residential water demand, but different demand is included for Residential sectors. A detailed forecast model would be required for large non-residential sectors (such as agriculture and industrial).

The model's accuracy will depend on the quality of the correlations between data and information and how the spatial extrapolations are conducted.

It should be noted that the model will need a forecast of the various independent variables that will be identified as having a meaningful influence on water consumption. These variables' predictions will mainly be based on the different areas' population growth and GDP predictions. However, some independent variables may show a temporal variation that is not necessarily linked to any of these two variables but to social or cultural changes that are difficult to predict.

The model is designed in an extremely flexible way, capable of handling almost any relationship between water consumption and the different variables collected.

It is good to mention that several economic, technological, and climatic factors may contribute to water consumption. For example, economic factors such as growth or recession can change the water demand for residential and non-residential. Also, the price of water will affect the amount of water used. Different sectors will respond differently to reducing their water consumption accordingly to these factors. Similarly, the technologies used within the sectors will also affect water usage rates. For example, newer buildings and more recent efficient technologies will have substantially lower water consumption rates than older buildings. All these factors combine to change the water consumption rates differently and make it almost impossible to make a fair comparison.

Based on the experience and insight gained over developing the thesis, here are key recommendations:

- The development of the bottom-up forecast model highlighted the need for solid statistical and water billing data. These form the forecast's starting point (basis) and must be available at a high enough resolution.
- A water distribution and metering infrastructure allow us to understand better how much water consume;
- Accurate customer billing data would improve the capacity to perform analysis on changes in water usage based on programs instituted;
- A regular audit of the technical and non-technical (or commercial) losses in the utility billing and metering system is also recommended. Besides, the implementation of Demand Side Management (DSM) Programs should be considered to assist in effectively managing water consumption.

This thesis can be further analyzed to serve other objectives: system planning, tariff setting, and bottom-line improvement.

6.2 Objectives achieved

After the conclusion of the thesis, it is worth reviewing to what extent the initial objectives that were set for the thesis have been achieved and fulfilled:

Main objective 1: Completely achieved.

Main objective 2: Mostly achieved.

Secondary objective 2.1 - Literature review: Fully achieved.
Secondary objective 2.2 - Model development: Fully achieved.
Secondary objective 2.3 - Implementation of the model: Partially achieved.

6.3 Particular conclusion focused on KSA

- Water security has multiple dimensions, including social, humanitarian, economic, and ecological. Therefore, major water resource management decisions must be made with broad cross-sectoral input.
- The current water allocations are not in line with the widely accepted water allocation guiding principle, which requires the water to be allocated to uses on which the society places the highest value. The current water allocations do not offer economic returns comparable to or higher than the opportunity cost of water.
- Water supply systems in KSA have evolved based on water resource availability. The major population centres on both coasts rely on supply from desalination plants, while the population on the Shelf mainly depends on non-renewable groundwater.
- Decentralized desalination and water purification facilities with a smaller footprint will reduce the impact of a single contamination event. They will provide redundancy so the water providers can maintain the quality should a facility go offline due to a natural or hostile act.
- Groundwater “urban supply protection zones” should be established in KSA by delineating and designating specific areas around or close to all major urban centres. Specific measures should be strictly implemented to prevent groundwater exploitation and water quality preservation in these zones.

- Continuation of the current practices, though has worked in the past, will start to cause economic pain.
- Reduction in municipal water consumption (national average) from the current 270 L/capita/day would need to be faced by politically challenging yet much required aggressive measures such as water tariff reform, leakage reduction, and aggressive campaign to increase public awareness on the importance of this precious resource for the current and future generations.
- If the share of desalinated water in the municipal water supply is 60%, this would mean recognizing that non-renewable groundwater is the Nation's strategic yet finite reserve. Every effort should be made to prolong the availability by using it for high-value uses.
- The MEWA water supply forecast, based on a fixed allocation, indicates a continuous increase in water requirements, which will accelerate the need for water supply expansions later. It also deviates from the actual supply in some areas, as it is impossible to pull back from very high per capita.

6.4 Future development

With the perspective of the work completed in this thesis, it is time to look ahead and identify the possible path that new developments derived from those contained in this document may follow.
These new developments are presented below in order of their direct relation to this thesis and the priority of their undertaking:

Future development 1: Complete the application of the developed model to a larger number of case studies.
This was one of the objectives of this thesis, which, however, could not be completed in its entirety. To give full coverage, it would be necessary to select a more significant number of municipalities in KSA according to their particular characteristics (size, urban density, predominant non-residential sector, specific restrictions on water resource availability, etc.) and apply the developed model to all of them, drawing the corresponding conclusions.

Future development 2: Carry out a sensitivity analysis of the main parameters of the model.
This analysis was not initially contemplated in the thesis presented here. However, it may be of particular interest. Indeed, the mathematical relationships embodied in the model may involve initially unexpected influences, or influences of unexpected magnitude, between the model's components. A sensitivity analysis of these components will reveal whether these influences may require new modifications.

Future development 3: Develop new consumption models for other non-urban water-consuming sectors.
Although the urban sector is the most essential water-consuming sector in KSA, as shown in the first two chapters of this thesis, other non-urban sectors (agriculture, oil exploitation) could benefit, through specific models, from the advances made in this thesis.

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ANNEX: ARTICLE IN JOURNAL WATER

ANNEX: ARTICLE IN JOURNAL *WATER* (DOI.ORG/10.3390/W14233828)

PROPOSAL OF A WATER CONSUMPTION EFFICIENCY INDICATOR FOR THE HOTEL SECTOR

Musaad Alhudaithi, Francisco J. Arregui, and Ricardo Cobacho

Abstract: This work proposes a novel indicator (HCWI) for evaluating water consumption efficiency in hotels. The indicator is built as a relative index that compares the current water consumption with an estimated minimum achievable value. To ensure the representativeness and applicability of the index, the evaluation of this water consumption baseline considers each water consumption micro-component individually and has been simplified, so it only requires fundamental characteristics of the hotel and those that are easy to identify and quantify. A value of the HCWI equal to one indicates the best water use efficiency that can be theoretically achieved with the technology available. On the contrary, larger values of the HWCI indicate high levels of water use inefficiency by the hotel. The applicability of the indicator is tested in six different hotels located in a touristic region in the north of Spain.

Keywords: hotel water consumption; efficiency; index; benchmarking

1. Introduction

The constantly growing pressure on natural water resources has led to scarcity problems in many arid and semi-arid regions such as the Caribbean, Mediterranean, and the Middle East [1–3]. Water availability problems are also expanding to humid areas, where the amount of rain is progressively decreasing. It is expected that water-related issues will increase in the medium and long term due to the larger world population and activity associated with economic growth. In such a scenario, assessing what consequences will appear in tourism, business travel, and the hotel industry in general will be necessary.

The hotel industry is one of the foundations of the tourism and business travel sectors. Neglecting the transitory effect of the COVID-19 pandemic, the continuous economic progress during the last century, and the reduction of travel costs have led to a significant increase in the number of pleasure and business trips [4–9]. Travellers are demanding high-quality accommodation with added-value services at reasonable prices. This is a significant challenge for the hospitality industry, which needs to adapt to stricter quality requirements by offering additional and better services that require less water and energy.

Furthermore, the war in Ukraine has led to an extraordinary energy crisis. In this context, given the well-known connection between water and energy consumption, it is crucial to examine the efficiency of water use in hotels. This analysis is necessary to assess the hotel industry's impact on local water resources, especially in tourist areas, and to propose genuinely effective water conservation measures to help reduce the environmental footprint. The sustainability of the tourism sector strongly depends on the adaptation capability of the hotel industry to the upcoming environmental conditions and the severer legal regulations that will be in place in the future [10,11].

A bibliographic review on the topic may emphasize the exhaustive research conducted about hotel industry sustainability and, more specifically, regarding hotel water consumption from multiple perspectives and approaches [12]. The presented work includes a literature review (Supplementary Material) in which previous studies analysing water consumption in hotels are described and explored in detail. From this analysis exercise, a substantial heterogeneity of water consumption in hotels was identified. Even the unitary water volumes used by different hotels in the same area, expressed in terms of per room or per guest, significantly differ from each other. In most cases, the results of the studies are merely descriptive [13,14] and cannot be employed to produce consistent relationships between different cases or regions, forecast water consumption, or calculate water use efficiency indexes.

Currently, there is no simple, generic, and robust procedure to estimate an achievable minimum water consumption figure for a hotel based on its characteristics and that could be used as a baseline or reference. A water consumption indicator obtained from this baseline could be convenient for assessing the gross efficiency of a hotel's current water consumption and comparing hotels of different sizes and facilities characteristics either in the same region or from different areas. Such a benchmarking tool, kept at a reasonably low degree of complexity, would be helpful for public administrations and regulators, hotel corporations, or small rural hotels keen on improving their environmental efficiency.

This approach is already employed in other sectors to compare the water loss efficiency of different water distribution networks through a relative indicator. In fact, an efficiency index complying with these characteristics has been used by utilities and regulators since 2000 [15] and has been proposed by the new European Directive [16] as a tool to assess water losses management performance by water utilities. Similar to what happens in the hotel industry, where every hotel has its own specific characteristics, each water distribution network also has its own particularities. This heterogeneity does not allow for an easy comparison of water losses between different systems. However, the publication of the infrastructure leakage index (ILI), which considers essential characteristics of the network, provided a compromised solution to the problem. Since then, this practical but straightforward indicator (ILI) has become a common benchmark worldwide for quantifying a distribution network's water loss management efficiency. The calculation of the ILI involves an estimation of the minimum amount of volumetric losses that could be achieved based on the characteristics of the network. The ILI informs about how many times the actual losses are above that minimum achievable value.

This work proposes a new indicator for evaluating water consumption in hotels (HCWI) that is calculated following similar principles as those used for calculating the ILI. This new indicator estimates the minimum achievable water consumption in a hotel based on its characteristics and different water uses (micro-components) and informs about how many times the actual consumption of the hotel is with respect to this minimum achievable volume. In other words, this indicator shows the improvement margin for water consumption reduction for a particular hotel if different efficiency measures are implemented.

In summary, the HCWI is not only a benchmark indicator between different hotels but also between the current hotel's water consumption and the hotel's consumption if water-efficiency measures were implemented. Therefore, the results obtained for that improvement degree can be directly comparable between different hotels.

2. Understanding Water Consumption in Hotels

Total water consumption in a hotel depends on various activities related to providing services and accommodation to guests that use water in one form or another. Previous works, which will be analysed in the next section of the paper (Section 3), have identified potential sources of water consumption within the hotel industry. These activities are commonly known as micro-components of water consumption and constitute the fundamental components of the total water use. Given the variety of accommodation types within the hotel industry, not necessarily all micro-components are present in a specific establishment. The following list briefly describes the various micro-components that have been identified for water consumption in hotels (Section 3) and the primary factors affecting each one of them.

Rooms: Guests' water usage inside hotel rooms is constrained to sanitary uses. This water use is comparable to the indoor consumption of a household restroom as the water appliances are the same: tap, toilet, bidet, and shower or bathtub.
As expected, water use inside guest rooms strongly correlates with the hotel occupation rate. The main influential factors identified for this micro-component are the following: technical characteristics of the water appliances, dynamic water pressure available at the consumption points, and consumption habits of guests.

Kitchen: Water use in a hotel's kitchen is extremely similar to water consumption in a restaurant's kitchen. It comprises meals preparation, kitchenware washing, and cleaning activities.
The magnitude of this micro-component depends not only on the hotel occupation rate but also on the possibility that the hotel restaurant is open to non-guests. In addition, the technical characteristics of the kitchen equipment (taps, dishwashers) are other influential factors.

Laundry: Water consumption associated with the laundry is required to wash towels, linen, and other clothes. Washing is typically done using industrial washing machines owned by the hotel or outsourcing laundry services to an external company. Water usage associated with this micro-component happens outside the hotel premises when this later situation occurs.
Similar to water usage inside rooms, water laundry consumption directly depends on the hotel occupation rate. The main relevant factor that affects its magnitude is the technical characteristics of the washers used and the linen replacement policies followed by the hotel.

Pools: As in the previous item, the water amounts required by the regular use of swimming pools, spas, or other water attractions also depend significantly on the type of hotel.
Hotel occupation rate has only an average influence on this micro-component because of the relatively high operation and maintenance flow rate in this type of installation. The main influential factors are the size of facilities and the hydraulic systems technology.

Irrigation: This micro-component accounts for the water required to maintain gardens and green areas. Irrigation depends hugely on the type of hotel: it may be negligible in urban business hotels, and conversely, it might demand significant amounts of water in the case of large holiday resorts.

Hotel occupation rate does not significantly influence irrigation water or, at least, not in the same proportion as other factors such as the size of gardens, irrigation systems, plant species, or the climate itself.

Cooling and heating: This micro-component includes the water required by the hotel's air conditioning (AC) system.
The amount of water used for cooling exhibits a medium dependence on the occupation rate of the hotel. The reason is that there are certain areas of the hotel, such as the reception, halls, corridors, the restaurant, or the gym, that need to be cooled independently of the hotel occupancy. However, other spaces, such as the guests' rooms, are only cooled if they are occupied. The main influential factor of this micro-component is related to the air conditioning system's technical characteristics and the climatic conditions at the hotel's location.

Following the previous description, Table 1 summarises the factors influencing the magnitude of each micro-component.

Table 1. Summary of characteristics of water consumption for each micro-component.

Micro-Component	Rooms	Kitchen	Laundry	Pools	Irrigation	Cooling and Heating
Aim of use	Sanitary	Meals preparation and cleaning	Clothes washing	Recreational	Garden watering	Air conditioning
Devices	Taps Toilets Bidets Baths Showers	Taps Dishwashers	Washers	Pools Spas Water attractions	Hoses Sprinklers Drippers	Cooling towers
Influencing factors	Technical features of devices	Technical features of devices	Technical features of devices	Climate and evaporation	Technical features of irrigation systems, type of plants, grass area	Technical characteristics of the AC system
Dependence on hotel's occupancy rate	High	High	High	Medium	Low	Medium

3. Literature Review and Conclusions

In order to set the context of this work, an extensive literature review was carried out. A total of 30 different specialised publications [17–46] were analysed from four different perspectives: year of publication, geographical location, number of hotels audited, and analysis methodologies used. The aim of this review was not only to determine reference figures for water consumption in hotels according to their characteristics but also to highlight how much dispersion there is in this type of data and how much variability, almost heterogeneity, can be found in the procedures behind it.

The detailed explanations and results of this review are included in the Supplementary Material. However, due to the variety of factors influencing water consumption and the dissimilarities between hotels, these reference values must be organised and presented from multiple perspectives.

It is unreasonable to compare hotels of different sizes directly, and their water consumption needs to be expressed using suitable relative indicators. Hence, water consumption from the various studies was recalculated with the information available to obtain relative consumption indicators. For this purpose, three essential characteristics of a hotel, which are easy to determine, were selected: floor area, number of rooms, and number of guests.

Relative daily total water consumption in hotels. Figure 1 presents the daily total water consumption from the 30 studies considered as a function of the selected three descriptive characteristics of the hotels. For each characteristic, a box-whisker chart shows the average value, median, maximum, minimum, and data dispersion of the compiled water consumption figures previously published.

This chart shows a substantial dispersion of the total water consumption volumes independently of the relative indicator considered. In all cases, the relative standard deviation, calculated as the ratio between the standard deviation and the average, is above 25%, with the less dispersed water consumption indicator as the one calculated per guest (relative standard deviation of 5.0, 509 and 247 for consumption per floor area, per room and per guest, respectively).

The average figures obtained, considering all 30 studies, for each indicator are the following:

Water consumption per floor area: 6.9 L/(m2·day)

Water consumption per room: 981 L/(room·day)

Water consumption per guest: 686 L/(guest·day)

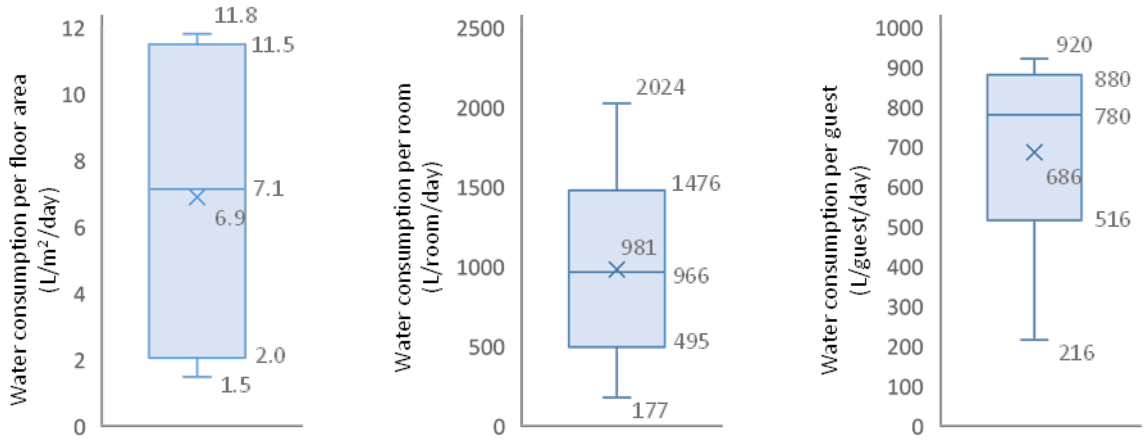


Figure 1. Box-whisker graphs for water consumption per floor area, room, and guest.

Relative daily water consumption per individual micro-component. A second-level examination disaggregates daily water consumption into the identified micro-components described in Table 2. Again, similar to the analysis conducted with the total consumption, these figures are expressed relative to the selected hotel's characteristics (floor area, number of rooms, and number of guests). The box-whisker graphs for the relative water consumption of each micro-component and its contribution to the total water consumption are shown in Figure 2 and Figure 3, respectively. It is to be noted that the contributions are expressed as a general percentage averaged from all the references reviewed. This means they should be understood as the average ones for an average hotel with all those facilities.

Table 2. Average daily water consumption for each micro-component.

Micro-Component	Rooms	Kitchen	Laundry	Pools	Irrigation	Cooling and Heating
Average consumption (L/room/day)	457	171	124	44	70	42
Contribution to total hotel consumption	35%	21%	15%	2%	18%	14%

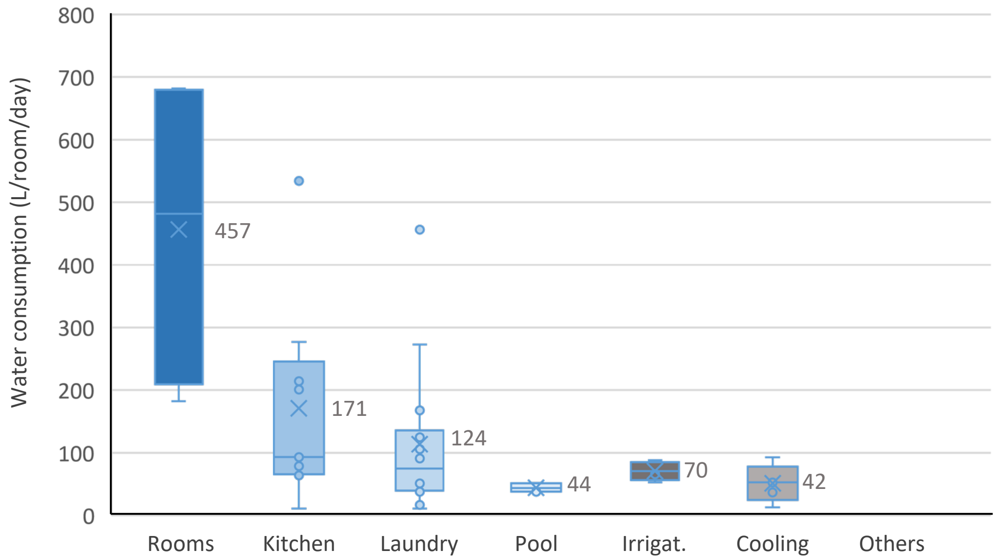


Figure 2. Distribution of daily relative water consumption per micro-component.

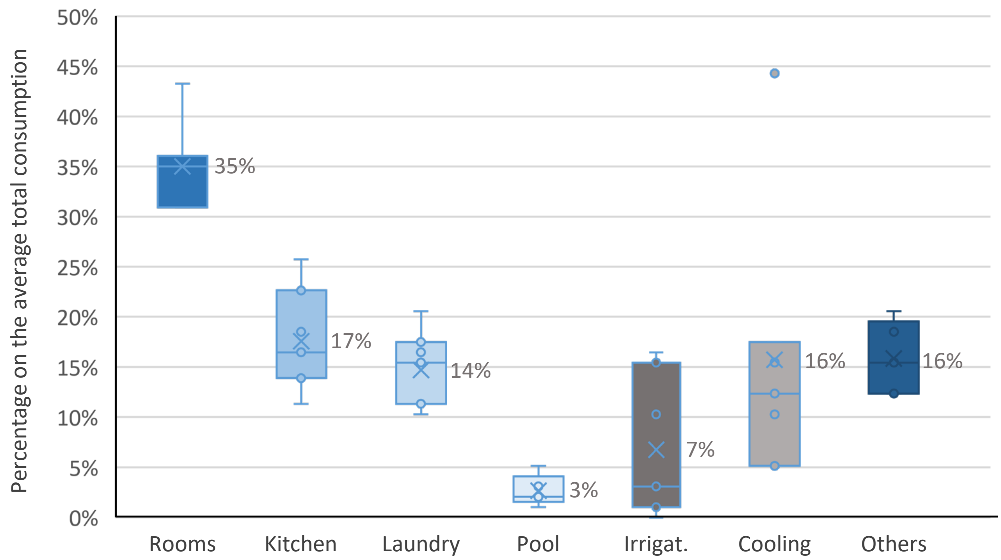


Figure 3. Contribution of each micro-component to daily water consumption.

4. Model for Water Consumption in Hotels

Given the variability found, the figures previously presented cannot accurately assess the consumption of a specific hotel or provide reliable information about how efficient water-related activities are. The contribution to the total water consumption of some micro-components can be estimated based on the entire surface area or the number of rooms. However, other components such as irrigation, cooling and heating, and the water use at a hotel's swimming pool strongly depend on specific characteristics of the establishment and the equipment installed that need to be considered in the calculations. In most cases, an average figure obtained from a literature review will not be helpful as a reference to estimate water consumption or to calculate an indicator for water efficiency performance.

For that reason, an accurate assessment of the hotel water usage and the potential efficiency improvements will require a detailed analysis of each micro-component. This approach might comprise complex multivariate regression calculations or equivalent statistical analysis methods (as followed by [14]).

The approach proposed in this paper aims to assess a hotel's water efficiency performance from a different perspective. It is similar to the methodology used to evaluate water losses in a distribution network and quantify its performance through a relative indicator [15]. The initial step is to build a simple consumption model for each water micro-component based on simple, measurable, and easily obtainable characteristics. Consequently, this model considers each hotel's specific features, local conditions, and environment that may affect its water consumption in a significant manner. Given its specific characteristics, this model allows the hotel administration to obtain a reference baseline figure for minimum achievable water consumption. Following the analysis, a second step compares the actual hotel water consumption with the calculated baseline figure. This comparison can be conducted globally or individually for each micro-component and will show the hotel's potential range of improvement for water reduction. In addition, it is possible to quantify the hotel's water efficiency and calculate a relative performance indicator. The following sections present the basic consumption model for each micro-component and, finally, the definition of the relative efficiency performance indicator.

4.1. Water Consumption in Rooms

Water consumption in rooms is, by far, the main component of the total water consumption in a hotel. At the same time, it is also the simplest one for analysis and modelling. Compared to other water micro-components, the type and variety of water uses within a hotel room are limited, and so are the factors affecting the amount of water used. In the literature, there is a general agreement about the following drivers for water consumption in hotel rooms:

1. The number of occupants in a hotel room is directly related to water consumption. An increase in the occupants' number implies a nearly proportional increase in water consumption.
2. The water consumption habits of the occupants affect the number of usages per day of the toilet and faucets or the running time of the showers and other faucets.
3. The number and type of water appliances can also influence the water volumes used inside guest rooms. Though hotel rooms tend to be comparable in number and type of appliances, the more sophisticated equipment in high-standard hotels (bidet, bathtub,

rain showerheads, hydro-massage showers, etc.) can lead to higher water consumption.

4. The water efficiency of the appliances installed. Independently of the type of appliance considered, it should be analysed if the service can be provided more efficiently. The objective is to perform its function and satisfy the customer's needs using the lowest volume of water.

In a standard hotel room, water can be used only by the appliances in the bathroom. These appliances may fall within two types:

- Flow rate-based appliances (faucet, shower, bidet). The consumption volumes from these appliances depend on the discharge flow rate and the running time. In addition, the flow rate depends on the available dynamic pressure at the room. The consumption volumes made by hotel guests can be calculated based on the average duration of the usage events and the average flow rates provided by the appliances.
- Volume-based appliances (toilet, bathtub). These appliances can be characterised by an average usage volume defined, for example, by the toilet tank size or the bathtub capacity. The consumption volumes are determined by estimating the number of times the guests in the room may use these appliances every day.
-

The proposed water consumption model inside guest rooms considers each type of appliance separately:

$$\mathrm{WD_R(L/room/day)} = \mathrm{N_G}\left[\sum_{i}(\mathrm{Q_i} \cdot \mathrm{t_i}) + \sum_{j}(\mathrm{V_j} \cdot \mathrm{n_j})\right] \tag{1}$$

where:
WDR is the average water demand per room (L/room/day);
NG is the average number of occupants per occupied room in the hotel. It is calculated by dividing the total number of hotel guests by the total number of occupied rooms. In general, it can also be considered as a characteristic parameter of the hotel. For example, in urban business hotels, NG might range between 1 and 1.5, while in holiday resorts, it can be as high as 2.5 or 3;
i stands for each appliance of flow rate-based type;
Qi is the average flowrate for each appliance i (L/min);
ti is the average time each appliance i is used per day (min/guest/room/day);
j stands for each appliance of volume-based type;
Vj is the average volume per use for each appliance j (L/use);
nj is the average number of uses per day for each appliance j (uses/guest/room/day).
It should be noted that, in Equation (1), the average time each appliance is used per day (ti) and the number of uses per day (nj) are defined as average values.

Reference values for standard and efficient appliances may vary according to the national standards applied in different countries. One of the best well-known references worldwide is the WaterSense programme [43] developed by the USEPA. That programme sets the technical specifications for the predominant water appliances, as shown in Table 3.

Table 3. Technical specifications for standard and efficient water use appliances

Water Appliance	Units	Standard	Efficient
Faucets	gpm	2.20	1.50
	L/min	8.33	5.68
Showerheads	gpm	2.50	2.00
	L/min	9.46	7.57
Toilets	gpf	1.60	1.28
	L/flush	6.06	4.85

Until today, many studies have analysed water consumption habits in different sectors and, in particular, in the hotel industry. The conclusions are frequently derived from surveys and questionnaires answered by final consumers (see Supplementary Material 1), which result in a highly unreliable picture of water consumption. Using more detailed and sophisticated analysis techniques, refs [47,48], summarised in Table 4, allow for a better modelling of water consumption characteristics. It is to be noticed that there is a significant difference between the results of both references. This is even though specific calculation and quantification work has been carried out in each case. The results presented only confirm that, although the expected variability of these figures is more or less limited, the real discrepancies between various situations can be very large.

Table 4. Average use-time (faucets and showerheads) and number of uses (toilets) per appliance.

Water Appliance	Variable (Unit)	[47]	[48]
Faucets	Time of use (min/guest/day)	1.6	4.8
Showerheads	Time of use (min/guest/day)	8.5	3.5
Toilets	#flushes (flushes/guest/day)	4.0	3.5

To calculate a reference for the minimum average water consumption per room (WDRMin), some minimum achievable figures for appliances and habits should be considered and applied to an average hotel room. The calculation has been conducted substituting the following values in Equation (1):

- Flowrates are the ones for efficient appliances in Table 3;
- Usage duration and number of flushes are selected from the ones within the range set by [47,48] in Table 4: 4.5 min/guest for faucets, 8 min/guest for showers, and 4 flushes/guest per toilets.

This way, the WDRMin can be calculated as

$$\mathrm{WD_{R_{Min}}}(\mathrm{L/room/day}) = \mathrm{N_G}\ [(5.68 \times 4.5 + 7.57 \times 8) + (4.85 \times 4)] = \mathrm{N_G} \cdot 105.5 \qquad (2)$$

The minimum consumption benchmark (MCB) associated with guests rooms (MCBR) should also take into account the total number of hotel rooms (NR) and the rooms occupancy rate (OccHotel). The OccHotel may vary significantly throughout the year depending on the type of hotel and customers and may follow a seasonal or weekly pattern. Consequently, to remove seasonality effects and conduct a more reliable assessment, extending the evaluation period of water consumption to a full year is recommended. Additionally, as litres are also translated into cubic meters, the constant 105.5 in Equation (2) turns into 38.5, and the MCBR can be expressed:

$$\mathrm{MCB_R(m^3/year) = 38.5 \cdot N_G \cdot N_R \cdot Occ_{Hotel}} \tag{3}$$

4.2. Water Consumption in Kitchens-Restaurants

Differences in kitchen water consumption between various hotels can be considerable. Parameters such as the size and number of restaurants, the type of cuisine, and the opening hours for customers significantly affect the total amount of water used in this activity. In consequence, the kitchen contribution to the entire hotel water consumption is hugely dependent on several factors:

- Factors affecting the number of meals served. These factors are related to size in general—the restaurant seating capacity, the working hours of the kitchen, or the number of meals shifts per day.
- Factors affecting the unitary water consumption per meal. These factors are either technical, such as the characteristics of appliances and machines used in the kitchen, or behavioural, such as the water consumption habits of employees. In addition, the type of cuisine may be relevant here. For instance, according to [49], Chinese kitchens may consume more significant amounts of water than others.

According to the previous factors, the proposed model for water consumption in a hotel each hotel kitchen can be expressed as

$$\mathrm{WD_K(L/restaurant/day) = C_{meal} \cdot N_{meals}} \tag{4}$$

where:
WDK is the average water demand per restaurant (L/restaurant/day);
Cmeal is the average water consumption per meal served (L/meal);
Nmeals is the total number of meals served (meals/restaurant/day).

Specific reference values for water consumption in hotels restaurants are not generally available. However, water consumption in single restaurants has been addressed in several studies [49–52], revealing a disparity of figures depending on various restaurant measurable features. The following list summarises the variation range of published results regarding the total water consumption in a restaurant kitchen as a function of different attributes:

Per surface area: 5.3 to 13.5 m3/m2/year;
Per meal served: 22.7 to 31.1 L/meal;
Per seat: 75.7 to 117.3 L/seat/day;
Per employee: 325.5 to 461.8 L/employee/day;

Restaurant figures could only be considered by taking into account two additional facts:

- Unfortunately, water consumption in a restaurant is not the same as in a hotel kitchen. Some water uses (restrooms, cooling and heating, cleaning, etc.) considered when calculating the water consumption in a restaurant are not present or have a minimal presence in a hotel kitchen. According to [50], only 52% of the total water consumption in a restaurant occurs in the kitchen.
- The references on restaurants cited above were focused on describing how and how much water is used but not on the potential reduction on water consumption if conservation measures were implemented. According to [53–55], the efficiency in a restaurant's kitchen could be improved up to an average figure of 35–40%.

From a conservative perspective, an efficient unitary water consumption per meal in single restaurants can be set at 23 L/meal. Considering the mentioned 52% to focus on kitchen consumption, a minimum value per meal results in 12 L/meal. Therefore, the minimum water demand for each hotel kitchen/restaurant can be calculated as

$$\mathrm{WD_{K_{Min}}(L/restaurant/day)} = 12 \cdot \mathrm{N_{meals}} \tag{5}$$

The number of daily meals served in a hotel depends on the number of guests staying (for clarity purposes, one restaurant will be assumed to be in the hotel). Secondly, it also depends on the time of the day, as most guests are likely to eat breakfast but not lunch. Thirdly, there is the possibility that hotel restaurants are open to non-guests. Thus, in the most popular restaurants, it may be the case that the number of dinners served is higher than the number of hotel guests. In order to relate the number of meals regularly served to the number of hotel guests, three coefficients have been considered: Kbreak, Klunch, and Kdinner. For example, typically Kbreak will be equal to one in holiday hotels where virtually all guests eat breakfast in the morning, Klunch will be significantly less than 1 in urban business hotels where guests often eat outside the hotel, and Kdinner will be greater than 1 in hotels where the restaurant is popular and receives external client for dinner. In conclusion, the number of meals can be parameterised as follows:

$$\mathrm{N_{meals}(meals/day)} = \mathrm{N_G} \cdot \mathrm{N_R} \cdot \mathrm{Occ_{Hotel}} \cdot (\mathrm{K_{break}} + \mathrm{K_{lunch}} + \mathrm{K_{dinner}}) \tag{6}$$

where:
Nmeals is the number of meals served per day;
NG, NR, and OccHotel are the same variables already explained;
Kbreak, Klunch, and Kdinner are the coefficients for breakfast, lunch, and dinner, respectively.

Therefore,

$$\mathrm{WD_{K_{Min}}(L/day)} = 12 \cdot \mathrm{N_G} \cdot \mathrm{N_R} \cdot \mathrm{Occ_{Hotel}} \cdot (\mathrm{K_{break}} + \mathrm{K_{lunch}} + \mathrm{K_{dinner}}) \tag{7}$$

As all the calculations are extended throughout the year, and litres are converted to cubic meters, the MCB for the water consumption in kitchens (MCBK) can be calculated as

$$\mathrm{MCB_K(m^3/year)} = 4.38 \cdot \mathrm{N_G} \cdot \mathrm{N_R} \cdot \mathrm{Occ_{Hotel}} \cdot (\mathrm{K_{break}} + \mathrm{K_{lunch}} + \mathrm{K_{dinner}}) \tag{8}$$

4.3. Water Consumption in Outdoor Irrigation

From urban hotels to vacation resorts, the irrigated area and type of gardens are incredibly heterogeneous. Whereas a small indoor gravel area with cacti and other succulent plants may require minimum water and maintenance, large turf areas or landscapes with beautiful leafy plants will account for a significant part of the total water demand of the hotel. The type of plants is crucial to determining the water amounts required for irrigation of green areas, but it is not the only factor. The main drivers identified by other authors [56–62] are the following:

- Climate. The first factor to consider is the general weather that naturally exists at the hotel geographical location. The better adapted the plants are to the local climate, the lower their water consumption.
- Garden area. The second factor is the size of the area to irrigate—the larger the area, the higher the water demand.
- Types of plants. From great water-demanding types such as turf grass to arid and semi-arid types such as succulent plants, the water requirements largely depend on the plant species selected for landscaping. It is essential to highlight that the ornamental value of plants must not necessarily be related to their water requirements.
- Irrigation system. The efficiency of the different irrigation systems available in the market might be highly variable. They can range from the lowest one, such as simple sprinklers, to the highest ones, such as drip irrigation managed through an automatic system driven by the hour of the day and the weather conditions.
- Additional means might also be installed to reduce plants water demand. In some cases, specific techniques such as mulching may reduce the water needs for irrigation.

There is general agreement on the most appropriate variables to model each of the above factors. Climatic conditions are represented by evapotranspiration, i.e., the amount of water lost to the atmosphere from a planted area due to (i) soil evaporation and (ii) plant transpiration. For each geographical location, evapotranspiration can be calculated as a final value (ET0) following a standard procedure on different climatic factors [63]: solar radiation, relative humidity, vapour pressure, air temperature, and average wind speed.

Similarly, the remaining determinants are generally represented by dimensionless efficiencies between 0 and 1. While there is a large consensus on the irrigation efficiency factor [59,60], approaches to model various plant types differ significantly. Some authors simplify it to a single element [59,61], while others include additional secondary components [62,64]. In summary, a basic calculation model for assessing the water demand for each garden area can be written as follows:

$$\mathrm{WD_I(L/garden/year)} = \mathrm{ET_0} \cdot \mathrm{A} \cdot \mathrm{PF} \cdot \frac{1}{\mathrm{K_r}} \cdot \mathrm{K_t} \quad (9)$$

where:

WDI is the irrigation water demand in a garden area (L/garden/year);

ET0 is the evapotranspiration reference value at the geographical hotel location (mm/year);

A is the garden area (m2);

PF is the plant factor for plant type;

Kt is the efficiency of gardening techniques;

Kr is the efficiency of the irrigation system.

Values for ET0 can be available from meteorological institutions or even from the literature (for example [65]). Such values accurately depend on the geographical location, but as guidance, Table 5 shows some general examples for different climate types.

Table 5. General ET0 ranges for different climate types .

Climate Type	ET_0 (mm/Year)
Cold tundra	0–400
Temperate regions	400–1000
Mild Mediterranean	1000–1500
Damp tropical regions	1500–2000
Arid zones	2000–2800

The plant factor (PFi) is related to the water requirements of each plant. The higher the value of PFi, the greater the amount of water the plant will need. Generic values of PFi for different plants can be easily found in the literature (for example [59, 61,62], Table 6).

Table 6. Examples of plant factors (PFi) for some different plant types .

Plant Type	PF_i
Turf (cool season)	0.8
Herbaceous perennials, annual flowers, bedding plants	0.6
Turf (warm season)	0.6
Woody plants (humid)	0.7
Woody plants (arid)	0.5
Desert plants	0.3

Depending on the irrigation system, a fraction of the watering will not reach the plants' roots or will be lost in another way. That means a loss of efficiency of the irrigation system employed (Kri), which is consistently lower than one, that must be considered in the calculations (for example [59], Table 7).

Table 7. Examples of efficiencies (Kri) for different irrigation systems .

Irrigation System	Kr_i
Sprinkler	0.75
Diffuser	0.75
Drip	0.90
Manual hosing	0.95

Sometimes, specific gardening techniques are available to reduce the natural ground evaporation or plant evapotranspiration. These gardening strategies allow for a reduction in the water volumes used for irrigation. In those cases, the efficiency (Kti) provided by those techniques should be considered in the calculations (for example [59], Table 8).

Table 8. Examples of efficiencies (Kti) for different gardening techniques .

Gardening Technique	Kt_i
Irrigation stepping	0.95
Mycorrhizae	0.80
Mulching (textile + bark clippings)	0.80
Mulching (textile + gravel)	0.75

To determine the minimum reference value for irrigation water demand, it is necessary to review the component variables (Equation (9)) one by one. ET0 is not eligible because it depends exclusively on the hotel's geographical location. The type of plant that minimises the irrigation demand should be the most suitable for the climate of the site; therefore, the PFi is ultimately dependent on that. The area of the gardens, Ai, depends on the type and configuration of the hotel. However, the irrigation and gardening coefficients should correspond to the techniques with the highest efficiency compared to alternative methods. According to Tables 7 and 8, the maximum feasible value of Kri and Kti is 0.95 for both of them. In conclusion, the minimum value of water demand for irrigation can be delimited as

$$\mathrm{WD}_{\mathrm{I_{Min}}}(\mathrm{L/garden/year}) = \mathrm{ET_0} \cdot \mathrm{A} \cdot \mathrm{PF} \qquad (10)$$

Finally, the hotel's benchmark for irrigation water consumption must consider its geographical location. For each of the three major inhabited climatic areas, results for MCBI are shown in Table 9, in which i stands for each of the garden areas in the hotel. It should be noted that the calculation of irrigation needs might be the most uncertain component of the hotel's MCB. The variability in meteorological conditions, characteristics of plant species, and the adaptability of the latter to the former can be much greater than that found for the other micro-components (attributes and use of taps, showers, washers, or even air conditioning systems). This should always be considered when performing these calculations and interpreting the results obtained.

Table 9. Values of MCBI for different climate types and types of plants.

Climate Type	ET_0 (mm/Year)	PF_i	MCB_I (m^3/Year)	
Temperate regions	700	0.7	$0.490 \cdot \sum_i (A_i)$	(11)
Mild Mediterranean	1250	0.6	$0.750 \cdot \sum_i (A_i)$	(12)
Damp tropical regions	1750	0.5	$0.875 \cdot \sum_i (A_i)$	(13)

4.4. Water Consumption in the Laundry

Hotel laundry is responsible for washing sheets, pillowcases, duvet covers, towels, tablecloths and napkins, and staff and guest linen. It typically uses considerable amounts of water in different processes, such as the washing and rinsing cycles of clothes in washing machines and devices such as steam-heated dryers, steam ironing equipment, and the reclamation of dry solvent [34]. Previous studies addressing this water use concluded that the volume used in the laundry might vary according to the following:

- Procedures for the use of washers. Full washer loads are more efficient than partial loads [26]. This is generally related to sports activities and health centres and the level of textile dirt [30].
- Technical characteristics of washers. Depending on the technologies employed, water consumption could vary as much as 70%: front-loading vs. top-loading washers [66,67], continuous-batch washers [34], or water reclamation systems that allow associating successive wash cycles by using the rinse water of the last washer as the load water of the next one [23].
- Working habits of laundry employees [40] and incentives for guests to reuse towels and bed linens [45] may make a significant difference. In extreme cases, outsourcing laundry services directly impacts laundry water [24,68].
- Specific conservation measures. Though the impact of conservation strategies vary from one case to another, reports show that water reductions up to 50% can be achievable [68,69].

A water consumption model for laundry should comprise two main components. The first one is the water consumption rate of the washing machine, expressed in litres per kilogram of laundry. The second one is the weight of clothes to be washed regularly. Under this consideration, laundry water demand can be expressed as

$$\mathrm{WD_L(L/laundry/day)} = \mathrm{C_W} \cdot \mathrm{N_C} \tag{114}$$

where:
WDL is the laundry water demand (L/laundry/day);
CW is the washer consumption factor (L/kg);
NC is the amount of clothes per guest that should be washed daily (kg/laundry/day).

There are various alternatives to express the amount of water used by laundry washers. Manufacturers' most widely used indicator refers to the water volume used per load. Typical water consumption figures per load for standard washers range from 57 to 95 L/load [66], whereas high-efficiency front-loading machines may use less than 49 L/load [70]. However, while this indicator is helpful for domestic washing machines with similar load capacities, it is not practical for industrial equipment with an ample range of sizes.

For this reason, the most suitable indicator to define the efficiency of a washing machine is the water factor [71]. This parameter quantifies the water volume used, in litres, per kilogram of clothes washed. The most common type of laundry machine is a washer-extractor, which operates with a rotating drum that agitates the laundry during the washing and rinsing cycles. It then spins it at high speeds to extract water and use fresh water for each wash and rinse cycle [34]. This type of washer has a capacity of 88 to 100 kg/load and consumes around 21 to 29 L/kg [34] or 8.3 to 16.7 L/kg [23]. Technical improvements in industrial washing machines have lately allowed a reduction of water consumption to 8 L/kg, and some devices achieve figures as low as 7 L/kg [37]. However, the most efficient laundry consumes around 5 to 6 L/kg [72,73], which allows expressing the minimum laundry water demand as follows:

$$\mathrm{WD}_{\mathrm{L}_{\mathrm{Min}}}(\mathrm{L/laundry/day}) = 5 \cdot \mathrm{N}_{\mathrm{C}} \tag{125}$$

The weight of the clothes to be washed daily depends very much on the hotel type, category, and of course, occupancy rate. The clothes requiring washing are mainly used in the rooms and restaurants by guests and employees in their daily activities. The working clothes of the staff might alternatively be considered as well, but in general terms, they are much fewer in number and represent less weight than the clothes used by guests. Therefore, for simplicity purposes, the working clothes of the staff will be neglected in the calculation proposed although they could be included if needed. Table 10 shows the reference weight for each type of cloth piece.

Table 10. Reference weight of most common clothes used by hotel guests.

Cloth Type	Mass (g)
Towel—big	600
Towel—medium	250
Towel—small	100
Bed linen	600
Pillow cloth	100
Duvet	800
Tablecloth	600
Napkin	20

The amount of clothes (NC) to be washed per day should be calculated separately for room clothes (NCR) and restaurant/kitchen clothes (NCK) since the clothes usage rates may differ significantly for each one. Then, considering the number of hotel guests and assuming that there is only one laundry in the hotel,

$$\mathrm{N}_{\mathrm{C}}\ (\mathrm{kg/day}) = \mathrm{N}_{\mathrm{G}} \cdot \mathrm{N}_{\mathrm{R}} \cdot \mathrm{Occ}_{\mathrm{Hotel}} \cdot \left(\mathrm{N}_{\mathrm{C}_{\mathrm{R}}} + \mathrm{N}_{\mathrm{C}_{\mathrm{K}}}\right) \tag{136}$$

where:
NG, NR, and OccHotel are the same variables already explained;
NCR is the amount of clothes per guest in rooms (kg/guest/day);
NCK is the amount of clothes per guest in kitchen-restaurant (kg/guest/day).

Table 11 shows the number of washes per day and guests expected for each room cloth type regularly, and Table 12 offers the washes per day and meal served in restaurants. Combining Tables 10 and 11 shows a global result of 1.46 kg/guest/day in rooms. In turn, the combination of Tables 10 and 12 yields 0.32 kg/meal/day in restaurants. As the meals per day has already been set above (Nmeals, Equation (6)),

$$\mathrm{N}_{\mathrm{C}}\ (\mathrm{kg/day}) = \mathrm{N}_{\mathrm{G}} \cdot \mathrm{N}_{\mathrm{R}} \cdot \mathrm{Occ}_{\mathrm{Hotel}} \cdot \left(1.46 + 0.32 \cdot (\mathrm{K}_{\mathrm{break}} + \mathrm{K}_{\mathrm{lunch}} + \mathrm{K}_{\mathrm{dinner}})\right) \tag{147}$$

Table 11. Average washes per guest and day for each cloth in rooms.

Cloth Type	#Washes Per Guest and Day
Towel—big	1

Towel—medium	1
Towel—small	1
Bed linen	1/2
Pillow cloth	1/2
Duvet	1/5

Table 12. Average washes per meal and day for each cloth in restaurants.

Cloth Type	Washes Per Meal and Day
Tablecloth	1/2
Napkin	2

Therefore,

$$WD_{L_{Min}}(L/day) = 5 \cdot N_G \cdot N_R \cdot Occ_{Hotel} \cdot \left(1.46 + 0.32 \cdot (K_{break} + K_{lunch} + K_{dinner})\right) \quad (18)$$

The MCB for laundry water consumption (MCBL) may finally be obtained by extending the calculations throughout the year and converting litres to cubic meters:

$$MCB_L(m^3/year) = N_G \cdot N_R \cdot Occ_{Hotel} \cdot \left(2.67 + 0.59 \cdot (K_{break} + K_{lunch} + K_{dinner})\right) \quad (19)$$

4.5. Water Consumption in Swimming-Pools

The contribution of swimming pools to the total hotel water consumption is highly dependent on multiple parameters that frequently are difficult to establish with sufficient accuracy. Among others, water consumption in a swimming pool depends on the type of hotel and clients' behaviours, the geographic location of the hotel, size and type of pool (indoor/outdoor), maintenance practices, local weather conditions, and the presence of leaks at the pipes and basin. Therefore, it is challenging to provide an exact figure of the lowest attainable water consumption without using complex equations and specific data of each swimming pool location and characteristic. The unavoidable water consumption in swimming pools is related to evaporation, backwashing of the filters, and often the legal obligation that applies in some countries to renew a certain percentage of the water of the swimming pool daily. Furthermore, splashing and showers can contribute significantly to total water consumption in swimming pools. While the first contributions depend on the hotel management, the lasts mainly rely on the behaviour of the users. Consequently, the control over this is more limited. To summarise, water consumption in swimming pools can be classified into the following categories:

- Evaporation. The amount of water lost depends on the temperature difference between the water and the surrounding air and other factors such as the relative humidity and the wind velocity over the pool [74].
- Maintenance tasks. Backwashing of the filters is a regular maintenance activity conducted periodically. The required frequency of backwashing depends on the number of swimmers and the dirt they introduce into the water. Even if proper maintenance is carried out, part of the water needs to be regularly renewed to adjust and correct the presence of chemicals and reduce the concentration of chloramines.

- Swimmers' activity. It is compulsory to shower for hygienic reasons before diving into a swimming pool. In addition, after taking a bath, it is highly advisable to take a shower to remove chlorine, bacteria, fungus, dead skin cells, hair, and other people's body fluids. Depending on several factors, splashing could be a significant component. It can be reduced by giving the proper slope to the wet deck and installing gutters around the pool's edge to collect most of the water splashed out.

Consequently, the model for water demand in swimming pools can be set as

$$\mathrm{WD_P} = \mathrm{WD_{Evap}} + \mathrm{WD_{Maint}} + \mathrm{WD_{Swimmers}} \tag{20}$$

where:
WDP is the swimming pool's total water demand;
WDEvap is the water losses evaporation in a swimming pool;
WDMaint is the water used in filters backwashing;
WDSwimmers is the water consumption due to swimmers' activity.

When totalling the volume of water used in pools, many authors only add the water losses caused by evaporation and splashing. For these subcomponents, their magnitude depends on the free surface area of the swimming pool, the water temperature and the air velocity above the pool, the relative humidity, and the average ambient temperature at the pool's location. There are significant differences between indoor [75] and outdoor [74] swimming pools concerning evaporated volumes. Ambient conditions at indoor swimming pools are typically well-controlled to maintain the users' comfort and can be estimated much more accurately, as they are kept stable throughout the year. In fact, indoor air ambient conditions should meet legal requirements in terms of relative humidity and temperature in most countries. Water consumption in outdoor pools caused by evaporation is less predictable, as it can significantly vary depending on the changing weather conditions.

A literature review on the topic can provide different methods of various complexities for estimating water losses due to evaporation and the type of use of the swimming pool. One of the most widely used methods for estimating evaporation losses is the one proposed by [76]:

$$\mathrm{WD_{Evap}}(\mathrm{L/pool/day}) = 15 \cdot 24 \cdot \ \mathrm{A_p} \cdot \mathrm{F_a}.(\mathrm{p_w} - \mathrm{p_a}) \tag{21}$$

where:
Ap is the pool surface area (m2);
Fa is the activity factor, which depends on the type of pool;
Pw is the saturation vapour pressure taken at the temperature of water at its surface (bar);
pa is the saturation pressure at ambient air dew point (bar).

Some countries require that part of the water volume be renewed daily regarding regular maintenance tasks. However, the new treatment technologies make this unnecessary, and this practice will reduce its contribution to the total water consumption in pools in the future. Therefore, as confirmed by [77], the everyday backwashing of the swimming pool filters is the most demanding operation. The frequency of backwashing and the time needed to clean the filters depend on the type of use, the concentration of hair and other organic materials, and other factors such as users coming to the swimming pool after going to a nearby beach. In summary [77], the backwash water totals about four times the pool volume per year.

$$\mathrm{WD_{Maint}(L/pool/day)} = \frac{4 \cdot 1000}{365} \cdot \mathrm{V_p} = 11 \cdot \mathrm{V_p} \tag{22}$$

where:
Vp is the pool volume (m3).

As mentioned above, the proper design of the swimming pool may nearly eliminate the splashing losses so that the primary water consumption by swimmers is the use of showers. Habits, pressure, and technical characteristic of showers have an influence, but in any case, it can be modelled using a unitary consumption of water per swimmer:

$$\mathrm{WD_{Swimmers}(L/pool/day)} = \mathrm{C_s} \cdot \mathrm{N_s} \tag{23}$$

where:
Cs is unitary water consumption per swimmer (L/day/swimmer);
Ns is the number of swimmers in the swimming pool.

Apart from the pool's features, all the other variables need to be quantified to assess the minimum achievable water consumption in a hotel swimming pool (WDPMin). Typical values for the parameters pw, pa, and Fa in Equation (21) can be found in the literature (for example [75]), and are presented in Table 13, Table 14, and Table 15, respectively.

Table 13. Saturation vapour pressure pw .

T (°C)	p_w (bar)	p_w (kPa)
15	0.0170	1.70
20	0.0234	2.34
25	0.0317	3.17
30	0.0425	4.25
35	0.0563	5.63
40	0.0738	7.38

Table 14. Saturation pressure at ambient air dew point pa .

T (°C)	40% Relative Humidity		50% Relative Humidity		60% Relative Humidity	
	p_a (bar)	p_a (kPa)	p_a (bar)	p_a (kPa)	p_a (bar)	p_a (kPa)
20	0.0094	0.94	0.0117	1.17	0.0140	1.40
25	0.0127	1.27	0.0158	1.58	0.0190	1.90
30	0.0170	1.70	0.0212	2.12	0.0255	2.55

Table 15. Typical activity factors .

Type of Pool	F_a
Residential pool	0.50
Condominium	0.65
Therapy	0.65
Hotel	0.80
Public, schools	1.00
Whirlpools, spas	1.00
Wave pools, slides	>1.5

For outdoor pools working with a dry bulb air temperature below 0 °C, the value is 0.0061 bar for pa. Alternatively, figures from Table 14 can be taken depending on the specific working conditions. Using this calculation methodology, in a worst-case scenario, an outdoor swimming pool in a hotel (with an activity factor of 0.8), taking pa as 0.0061 bar, with a saturation vapour pressure at 25 °C of 0.0317 bar, will lose 7.4 L/m2/day. Following an equivalent calculation, the evaporation loss for an indoor pool is about 4 L/m2/day.

Rather than its capacity, the surface area is the main and most variable dimension of a swimming pool. Besides that, particularly in hotels, the depth can be simplified to 1.5 m on average.

According to [78,79], the average water used per swimmer ranges from 40 to 60 L/day/swimmer. In conclusion, the minimum water demand per day for an outdoor swimming pool may be estimated:

$$\mathrm{WD}_{\mathrm{P_{Min}}}(\mathrm{L/pool/day}) = 7.4 \cdot \mathrm{A_p} + 11 \cdot 1.5 \cdot \mathrm{A_p} + 40 \cdot \mathrm{N_s} \qquad (24)$$

In the case of bulk estimations, for which the number of swimmers, Ns, could not be easily available, it could be taken into account that official standards generally regulate the maximum bathing load through the pool area. For example, [80,81] set an average ratio of 2 m^2/swimmer.

To extend the calculation of WDPMin to a full year and obtain the MCBP, the number of days the pool is open has to be taken into account. Here, it will be better considered as the percentage of open days over 365 days (PoolOpen):

$$\mathrm{MCB_P}(\mathrm{m^3/year}) = 0.365 \cdot \left(23.9 \cdot \mathrm{A_p} + 40 \cdot \mathrm{N_s}\right) \cdot \mathrm{Pool_{Open}} \qquad (25)$$

4.6. Water Consumption in Air Conditioning

Various types of heating, ventilation, and air conditioning (HVAC) require cooling towers to work. A cooling tower transfers waste heat to the atmosphere from a coolant, typically water, that evaporates when it circulates through an airstream [33]. The volume of water evaporated in the cooling tower implies that a portion of the water used in the cooling process is lost by misting and drifting away. Because of this, cooling towers are considered one significant cause of the increase in water consumption in the commercial and industrial sectors [33]. The quantity of water used by this type of system depends on several factors:

- The system technology and design. The water demand in an open-loop cooling tower is much greater than that for a closed-loop device. Not only that, but closed-loop devices have shown significant advantages and better overall efficiencies than the alternative open-loop system [27]. Equally, feasible modifications on existing systems such as eliminating single-pass cooling, increasing the tower's cycles of concentration, or improving total operational management have reported significant reductions in water consumed [82]. Finally, other aspects such as the design loads performance [83] and the maintenance level [34] have shown an evident influence on water consumption.
- Characteristics of the building. The size of the building and, more particularly, the space being cooled and heated is the main factor for the water consumption of the

cooling system [51]. Other features such as the building design criteria and the average and maximum occupancy [51] should also be considered.

A full-detail model to calculate the expected water demand of a hotel cooling system should be based on the system's technical characteristics, the local weather conditions, and the total space (volume) of the building to be cooled. However, from a practical point of view, such an approach cannot be easily implemented and integrated into a model in which the main drivers are the number of rooms, number of guests, and other quantifiable variables. For simplification purposes, a model based on the hotel's public (shared) spaces and the number of occupied rooms is proposed:

$$\mathrm{WD_{AC}} = \mathrm{WD_{AC_{Occupied\ rooms}}} + \mathrm{WD_{AC_{Common\ areas}}} \tag{26}$$

The water requirements for the air conditioning of occupied rooms depend on the water consumption of the air conditioning system per room and the number of occupied rooms:

$$\mathrm{WD_{AC_{Occupied\ rooms}}(L/AC\ system/day)} = \mathrm{C_{AC}} \cdot \mathrm{N_R} \cdot \mathrm{Occ_{Hotel}} \tag{27}$$

where:
WDAC Occupied Rooms is the water consumption of the air conditioning system for occupied rooms (L/AC system/day);
CAC is the unit water consumption per room of the air conditioning system (L/room/day);
NR and OccHotel are the same explained above.

Assessing the water requirements for the air conditioning of the hotel common areas (lobby, corridors, restaurants, etc.) involves a more significant number of uncertainties. On the one hand, common areas are constantly air-conditioned, whereas the system may be switched off in rooms while their occupants are away. On the other hand, the size of the common areas can be much more variable and challenging to assess than in rooms. To keep a straightforward approach, this component will be set as a constant value after applying a given percentage, 15%, on the total water requirements to air conditioning all the hotel rooms, no matter the particular occupancy rate at any moment:

$$\mathrm{WD_{AC_{Common\ areas}}(L/AC\ system/day)} = 0.15 \cdot \mathrm{C_{AC}} \cdot \mathrm{N_R} \tag{28}$$

In summary, and assuming one AC system in the hotel,

$$\mathrm{WD_{AC}(L/day)} = \mathrm{C_{AC}} \cdot \mathrm{N_R} \cdot (\mathrm{Occ_{Hotel}} + 0.15) \tag{29}$$

References on water consumption rates for air conditioning systems range significantly from 274 L/room/day in [18] to 27–53 L/room/day in [27]. From a conservative perspective, the minimum efficient consumption could be set at

$$\mathrm{WD_{AC_{Min}}(L/day)} = 25 \cdot \mathrm{N_R} \cdot (\mathrm{Occ_{Hotel}} + 0.15) \tag{30}$$

If the hotel occupancy rate is considered, and water consumption is calculated for a whole year, the MCB for air conditioning (MCBAC) is obtained as

$$\mathrm{WD}_{\mathrm{AC}_{\mathrm{Min}}}(\mathrm{L/day}) = 25 \cdot \mathrm{N_R} \cdot (\mathrm{Occ_{Hotel}} + 0.15) \tag{30}$$

5. The Indicator: Hotel Water Consumption Index (HWCI)

All the MCB presented above can be easily calculated for any hotel since they rely on a few essential characteristics: number of rooms (NR), number of seats in the restaurant (NS), number of meals served per day (NM), geographical location, garden area (Ai), swimming pool area (Ap), average number of swimmers (N), restaurant occupancy rate (ResReat), and room occupancy rate (OcRate). By adding all the MCB obtained, the total minimum consumption benchmark for the whole hotel can be calculated:

$$\mathrm{MCB}\ (\mathrm{m^3/year}) = \mathrm{MCB_R} + \mathrm{MCB_K} + \mathrm{MCB_I} + \mathrm{MCB_L} + \mathrm{MCB_P} + \mathrm{MCB_{AC}} \tag{32}$$

The MCB obtained represents a minimum reference value for the hotel's total annual water consumption. The hotel water consumption index (HWCI) is now defined as the ratio between the current hotel annual water consumption and the MCB:

$$\mathrm{HWCI} = \frac{\text{Current annual water consumption } (\mathrm{m^3/year})}{\mathrm{MCB}\ (\mathrm{m^3/year})} \tag{33}$$

In conclusion, the HWCI shows a direct comparison between the current water consumption in a hotel and the minimum water consumption that could be still achievable in practical terms. In other words, the indicator shows the number of times the current consumption is greater than it could be under the most efficient reference conditions.

6. Case Study

The HWCI was calculated for six hotels. All of them are located in a touristic region in the north of Spain (temperate, relatively humid European area with cold winters and moderate summers).

For confidentiality purposes, the hotels will be named only as H1 to H6. However, all their main characteristics, used in the calculations, are depicted in Table 16. The hotels vary from a small high-standard historic urban hotel (H2) to a large business and touristic urban hotel (H5) or a small countryside hotel (H4). The individual occupation rate for each hotel was not directly available, so general data on average hotel occupation for each year (Table 17) were obtained from the official tourism organism in the region [84] and applied equally for all six hotels. Because of the same reason, the average room occupancy (NG) was kept to one. Actual monthly water consumption for each hotel was provided from year 2017 to year 2020 (Figure 4). Total consumption for each year is presented in Table 17. It is to be noticed that hotels H5 and H6 stopped all activity during the COVID-19 pandemic in 2020.

Table 16. Hotels' main features.

Hotel ID		H1	H2	H3	H4	H5	H6
Hotel Style		**Rural Business**	**Urban Luxury**	**Urban Budget**	**Rural Small**	**Urban Business**	**Urban Luxury**
Number of Rooms		114	36	76	42	200	145
Restaurant's coefficients	Breakfast	1	1	1	1	1	1
	Lunch	0.5	0	0.3	0.7	0.7	0.5
	Dinner	1.2	0	0.5	1.5	1	1.2
Garden area (m^2)		12,500	0	0	3000	465	0
Swimming Pool	Area (m^2)	0	0	0	100	175	0
	% Open	0	0	0	0.25	0.25	0
	Swimmers/day	0	0	0	15	30	0

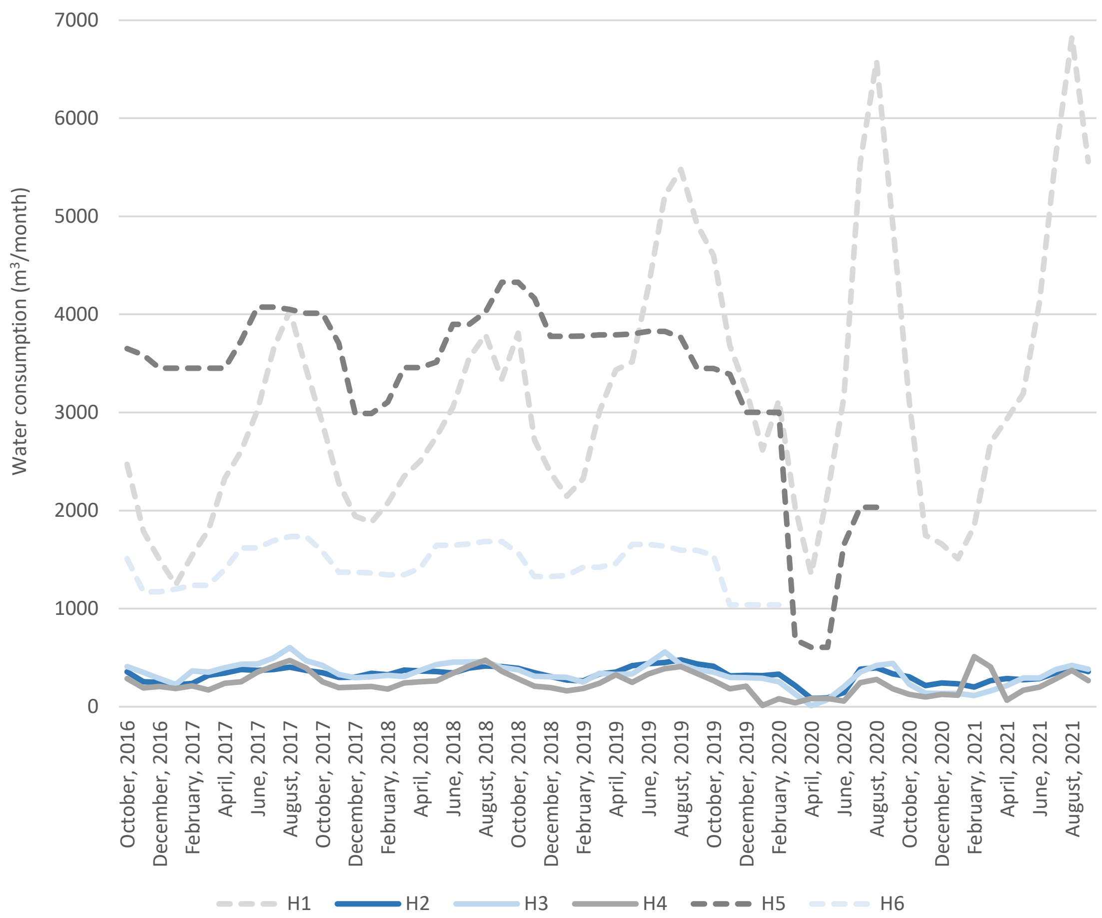
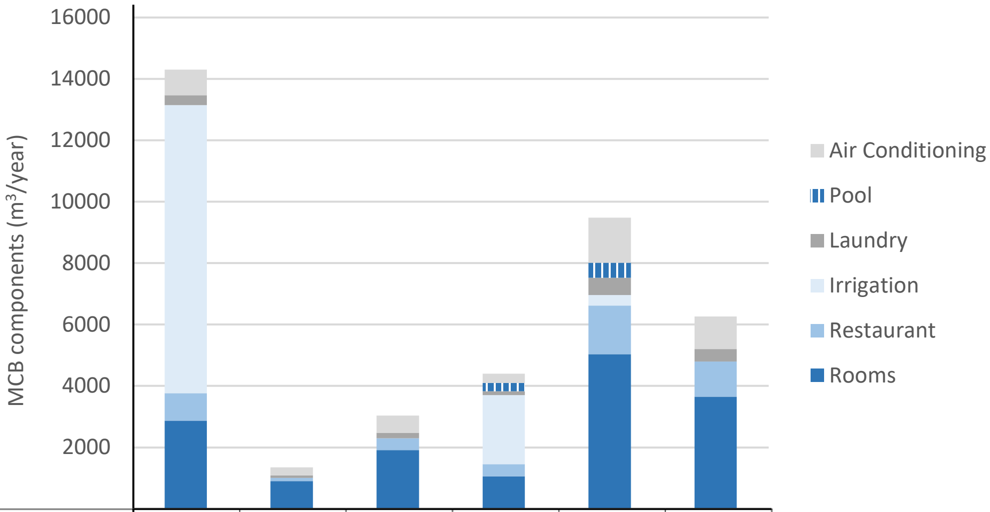


Figure 4. Water consumption per hotel and month.

Table 17. Hotels' water consumption during the later years and average occupation rate.

Hotel ID	Actual Water Consumption for Each Hotel (m^3) H1	H2	H3	H4	H5	H6	Average Occupation Rate Per Year
2017	30,783	3972	4827	3349	44,462	17,798	65.4 %
2018	34,226	4371	4491	3430	44,946	18,013	67.5 %
2019	45,834	4488	4314	3289	43,642	17,403	68.4 %
2020	38,013	3058	2674	1417	-	-	41.0 %

The MCB can be obtained, component by component (Equations (3), (8), (11)-(13), (19), (25), and (31)). Figure 5 shows the particular results for each hotel in the year 2017 (65.4% occupation rate).



m³/year	H1	H2	H3	H4	H5	H6
Rooms	2872	907	1914	1058	5038	3652
Restaurant	898	103	381	391	1575	1142
Irrigation	9375	0	0	2250	349	0
Laundry	318	76	183	125	559	405
Pool	0	0	0	273	491	0
Air Cond.	836	264	558	308	1467	1064
Total MCB	**14,299**	**1351**	**3036**	**4405**	**9479**	**6263**

Figure 5. Micro-components for the calculation of MCB for all six hotels in year 2017.

In Figure 5, the weight of the different characteristics of each hotel on its total MCB can be better appreciated, for example, the importance of garden irrigation versus the low number of rooms in H1 and H4 or also,, conversely the high number of rooms in H3 and H5 given their eminently urban character.

The same calculations were then performed to obtain the MCB for each hotel from 2017 to 2020, and the final value of HWCI for each hotel and year was obtained (Table 18). A general review of HWCI revealed that the most efficient hotel in water consumption is H4. In all the years, its HWCI falls below one. In principle, this is a strange result because it means that the actual water consumption in that hotel is lower than the ideal, most efficient one. However, as it is the case of the ILI for water losses [85], the HWCI is also an estimation based on experience and literature; therefore, cases like this one are not common but may be possible. One more aspect not to be neglected is that H4 is the second hotel with the largest green area. As explained in Section 4.3, the uncertainty behind the calculation of irrigation needs could influence the particular result for H4. Hotel H3 remains at water consumption levels very close to its minimum efficiency (HWCI ≈ 1.5). Hotels H1, H2, and H6 would be in the next tier of water inefficiency (HWCI ≈ 3.0), and finally, H5 would be the most inefficient hotel in water consumption (HWCI > 4.5).

The evolution of the HWCI for each hotel during these four years is shown in Figure 6. H1 and H2 show an upward trend in HWCI during the four years. This means that their actual water consumption grew more than their MCB, revealing a decline in water efficiency during those years. Conversely, the other hotels, H3 to H6, show a reduction in HWCI, which means an increase in water consumption efficiency. In any case, Figure 6 shows that the special conditions of the pandemic in 2020 did not significantly change the water efficiency trend each hotel had during the previous years.

Table 18. HWCI results for all six hotels from 2017 until 2020.

Year	Avg. Occ. Rate		H1	H2	H3	H4	H5	H6
2017	65.4%	Actual consump. (m^3/year)	30,783	3972	4827	3349	44,462	17,798
		MCB (m^3/year)	14,299	1351	3036	4405	9479	6263
		HWCI	2.2	2.9	1.6	0.8	4.7	2.8
2018	67.5%	Actual consump. (m^3/year)	34,226	4371	4491	3430	44,946	18,013
		MCB (m^3/year)	14,452	1392	3130	4464	9748	6458
		HWCI	2.4	3.1	1.4	0.8	4.6	2.8
2019	68.4%	Actual consump. (m^3/year)	45,834	4488	4314	3289	43,642	17,403
		MCB (m^3/year)	14,518	1410	3171	4489	9863	6542
		HWCI	3.2	3.2	1.4	0.7	4.4	2.7
2020	41.0%	Actual consump. (m^3/year)	38,013	3058	2674	1417	-	-
		MCB (m^3/year)	12,520	865	1942	3724	6358	4001
		HWCI	3.0	3.5	1.4	0.4	-	-

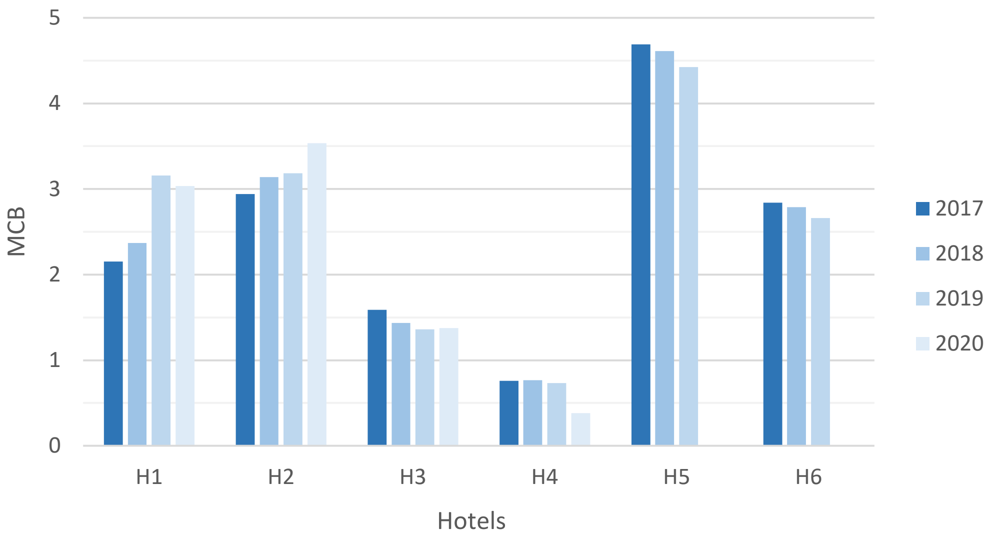


Figure 6. HWCI results for all six hotels from 2017 until 2020.

7. Discussion

By its very definition, the function of the HWCI is to assess the efficiency of a hotel's current water consumption or, in other words, the ability of a hotel to reduce it while maintaining an adequate level of satisfaction of its guests. It is important to distinguish between this function of the HWCI and other possible yet different environmental assessments that can also be made on a hotel's operation.

For example, the HWCI outcome is independent of the possible different water sources a hotel can use. Water reuse can be of great importance [86–88], as it reduces the hotel's impact on water resources. However, such reuse can involve significant costs (energy, reagents), so the positive impact on the resource could be overshadowed by such increased costs. To be aware of this, and to avoid it as much as possible, it is necessary to ensure that final water consumption itself is kept at a low level, and this is precisely the function of the HWCI.

Desalination of seawater or brackish water has also been studied [89–92]. Again, these cases involve a variation in the hotel's water balance (public distribution network versus own resources), but their environmental impact could be negative due to a possible lack of control (overexploitation of aquifers), not to mention the increase in energy these options imply. Again, ensuring that end-use consumption is close to its technical minimum (HWCI) is a necessary condition for an adequate exploitation of these resources.

Other approaches from a broader perspective, such as emissions or life cycle analysis [93–95], are more distant from the present work, but still, they ultimately depend on the overall level of resources consumption of the hotel, and water is a basic component of it.

Thus, the HWCI proves to be an essential indicator that can contribute to the different types of studies mentioned above. Moreover, for all of them, it is necessary to go deeper into the particularities of each hotel, which complicates each individual analysis and prevents broad comparisons. Precisely, the potential of the HWCI lies in fully assessing water use in a way that is consistent and supported by the current state of the art and simple enough in terms of calculations and data to make it extensible to benchmarking work. This is the main aim of the HWCI, but in addition, we can list the following additional advantages:

a. The HWCI efficiency indicator takes into account and evaluates all the existing water consumption micro-components in any hotel separately. The minimum achievable water consumption in a hotel is calculated by summing the minimum water consumption achievable in each micro-component, considering the hotel's characteristics.

   This structure allows the HWCI to be easily adapted to any hotel. For example, if a hotel does not have a swimming pool or if it has outsourced a service such as laundry, those components can be eliminated from the final calculation of the HWCI. From a global perspective, an outsourced service does consume water, and it should be taken into account in externalities or life cycle analyses, but they are outside the strict management of the hotel's scope, which is the HWCI.

b. The figures obtained for the HWCI are independent of the local conditions, hotel style, or other factors that may influence water consumption. The HWCI considers and reduces the dependence on these and other hotel characteristics related to water consumption components. This way, the HWCI figures can be used for a more reliable comparison of the efficiency performance of different accommodation establishments;

c. Regardless of the above, the HWCI has been designed to have a simple calculation procedure, and the parameters needed can be directly obtained and verified by external auditors. The HWCI calculation only requires eight primary hotel attributes. The proposed figures for the parameters used in the calculation are justified according to the current state of the art and previous publications. The operations to be performed are neither mathematically nor statistically complex;
d. The HWCI is easy to understand, and it can be directly compared to a reference value: one. The greater the HWCI, the less efficient hotel's water use is. The HWCI is a non-dimensional index that reflects the inefficiencies related to water consumption and how many times above the minimum achievable amount the current consumption of the hotel is. It also reflects how much room is available to implement water efficiency measures, quantifying the magnitude of the attainable savings and providing indication where to apply them.

The authors also would like to highlight the main drawbacks of using the proposed indicator:

e. The HWCI is based on figures representative of current conditions. As such conditions might change in the future, the HWCI calculations should be updated accordingly. This may be especially relevant for the case of new technologies in consumer devices that may be developed and thus reduce the minimum achievable consumption in some microcomponents. Likewise, ET0 values can be updated as climate change studies confirm them;
f. The calculation of the HWCI has been proposed on an annual basis because it is intended for long-term analysis, and the usual reports on occupancy, consumption, and even climatic parameters are all prepared on an annual basis. However, this does not prevent the HWCI from being used for the analysis of shorter time periods. In the case of hotels with a highly seasonal occupancy that may also be located in climates with very distinct seasons (such as the Mediterranean climate), an annual average may not represent properly the hotel operation. Alternatively, the hotel management may want to know in more detail the water efficiency consumption in each season since the maximum occupancy and water consumption normally match the highest temperatures. In such cases, calculating the HWCI for a period of three months (or any other duration) is not a problem. It is sufficient to know the value of all the calculation parameters for that period of time. Although some of them will be constant (flow rates or consumption times), it will be the most critical ones (occupancy, temperatures, rainfall) that will make the difference;
g. The HWCI relies on the previous calculation of the MCB. It is essential to highlight that the MCB is solely a reference for the hotel's minimum achievable water consumption. The MCB does not provide a figure for the actual minimum achievable water consumption for the specific conditions of the establishment analysed. This way, values of HWCI below one should not be frequent but are not impossible (as in the case of H4 in the previous section). HWCI below one should be interpreted as belonging to hotels with fully efficient water consumption. HWCI above one should not be considered an unacceptable result without a detailed analysis;
h. There is a risk of manipulating the parameters used to calculate the minimum achievable consumption to obtain lower values for the HWCI. Consequently, a complete

understanding of the indicator requires that the report also includes a comprehensive justification of the parameters used in the calculation.

8. Conclusions

As shown in the case study, the HWCI contributes to a better understanding of the potential sources of water inefficiencies and the selection and design of mitigation measures.

When properly used, this indicator provides much more information than a single index and facilitates the comparison of hotels of various characteristics located in different geographical areas. This way, the HWCI could become a valuable analysis tool at different levels. At the level of a single hotel management, the HWCI allows not only to identify options for improvement in water use but, above all, to carry out continuous efficiency monitoring over time in a consistent manner and to evaluate the results of the various actions that are being implemented. At the hotel chain management level, the HWCI, being a relative indicator, is helpful for benchmarking exercises—either considering different hotels at the same time or tracking the outcome of possible water efficiency policies in various hotels along time. Finally, at the public policymakers level, the HWCI could help to identify efficiency gaps in the water consumption of the hotel sector or even set the standard that could be required in the future.

As experience has shown for the case of ILI in the management of water distribution networks, the advantages of HWCI for assessing the efficiency of water consumption in hotels clearly exceed its disadvantages for a better environmental performance.

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