Decadal Variation of Aridity and Water Balance Attributes at the Urban and Peri-urban Environment of Attica-Greece

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Abstract

Aridity and changes of the water balance attributes can have a significant impact on the vegetation patterns in both urban and rural environments. In this work, the decadal changes of water budget related attributes (precipitation, potential evapotranspiration, water deficit and surplus) are investigated in conjunction with indices used in climate classification as the Thornthwaite's Aridity Index (AI), the potential evapotranspiration PET percentage of the drier trimester to the PET of the decade (CEET), the ratio of the average annual decadal precipitation to the average annual precipitation of the total timeseries (RPI) and the Moisture Index (MI) in order to assess the climate variability patterns in an urban and a peri-urban site in the region of Attica, central Greece. Result indicate major changes through the recent decades for most of the examined parameters to more arid conditions with more limited water availability for the vegetation, while these change are more rapid and severe in the urban areas.

Keywords

Climate, Aridity, Attica, Thornthwaite, UNEP

1. Introduction

Precipitation and soil water availability can highly affect plants growth rates and dynamics [1,2] due to their impact in evapotranspiration rates. The urban infrastructures appears to play also a very significant role in determining the urban climate [3-5]. The frequent and long lasting droughts [6], in conjunction with the continuously changing climate in the Mediterranean and specifically in Greece [7-11] underline the need for continuous monitoring of climate attributes in order to evaluate possible current or future effects on natural or urban vegetation. This is critical considering that the Mediterranean climate is characterized by rapid changes, relatively low water availability and increased deficits especially during the periods that plants have high water requirements.

The purpose of this study is to investigate the changes of aridity and related parameters to the water balance in an urban and a peri-urban site in Attica, which is a region of Greece that is highly affected by urbanization within the last decades. The climate attributes were studied by using long term meteorological data (1955-2019) on a decadal time-step, under the framework of the water balance approach proposed by Thornthwaite [12] and revised by Thornthwaite and Mather [13, 14], which is the base of UNEP's [15] aridity climate classification system that is widely used in climate research. The present study may be considered as a useful for detecting possible future risks on a local lever and for adopting measures for more sustainable urban design in Mediterranean cities.

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2. Study Area and Data

This work was implemented for the broader area of Attica. Long-term meteorological data obtained from two stations located near the urban (N. Filadelphia) and the peri-urban (Tatoi) environments of Attica were analyzed. More specifically, monthly precipitation data for the station of N. Filadelphia (38° 03' N, 23° 40' E, alt. 12.0 m a.s.l.) were obtained by the station owned by the Hellenic National Meteorological Service (HNMS) and cover the time period 1955-2010. The monthly average air temperature data series for the same station were available for the period 1955-2018. For both time series, the monthly gaps for the year 2019 (for air temperature) and years 2012-2019 (for precipitation) were filled by the nearby operating station (38° 02' 00'' N, 23° 42' 00'' E, alt. 87 m a.s.l.) owned by the National Observatory of Athens (NOA) (https://www.meteo.gr/).

To assess the peri-urban environment of Attica, data from the meteorological station of Tatoi were used. The station is located at the downhill of Parnitha's mountainous forest, which has been declared as a National Forest and is also protected as a Natura 2000 site. The station, owned by HNMS, is located in 38° 06' N, 23° 47' E, alt. 236.0 m a.s.l. and has available monthly average air temperature and precipitation data for the time period 1955-2017. The time-series of this station for the years 2018 and 2019 were obtained from the nearby operating station of NAO (38° 06' 00'' N, 23° 48' 00'' E, alt. 283 m a.s.l.). From the above monthly data, the decadal time-series were produced for this work, as averages of the time periods 1955-1959 (1950's), 1960-1969 (1960's), 1970-1979 (1970's), 1980-1989 (1980's), 1990-1999 (1990's), 2000-2009 (2000's) and 2010-2019 (2010's).

The decadal data were used to assess the aridity and the water balance in the two sites. Both aridity and water balance related attributes (water surplus S and water deficit D) were estimated by Thornthwaite's water balance approach [12-14], assuming that the soil water holding capacity is equal to 300 mm for a soil depth of 150cm that is proposed for silt loam soils [16] and is generally accepted for climate assessment in Greece [11, 17]. The potential evapotranspiration PET was estimated according to Thornthwaite [12], whereas UNEP's [15] aridity index (AI) was applied for the climate classification in different aridity classes: hyper-arid HA (AI<0.05), arid A (AI=0.05-0.20), semi-arid SA (AI=0.20-0.50), sub-humid SH (AI=0.50-0.65) and humid H (SA>0.65). Climate subtypes were also defined based on PET annual values:

- E' (glacial, PET<142 mm),
- D' (tundra, PET=142-285 mm),
- C'_1 (microthermic, PET=285-427 mm),
- C'_2 (microthermic, PET=427-570 mm),
- B'_1 (mesothermic, PET=570-712 mm),
- B'_2 (mesothermic, PET=712-855 mm),
- B'_3 (mesothermic, PET=855-997 mm),
- B'_4 (mesothermic, PET=997-1140 mm) and
- A' (megathermic, PET>1140 mm).

Moreover, the assessment was performed by the study of the Moisture Index (MI) described in Thornthwaite and Mather [13] as the difference between humid (I_h=S/PET) and arid (I_a=D/PET) indices that also define different climate sub-categories (A, B, C, D and E climatic types and d, r, s and w sub-types). In addition, the potential evapotranspiration PET percentage of the drier trimester to the PET of the decade CEET was also used for the classification to different climate sub-types:

- a' (CEET<0.480),
- b'_4 (CEET=0.480-0.519),
- b'_3 (CEET=0.519-0.563),
- b'_2 (CEET=0.563-0.616),
- b'_1 (CEET=0.616-0.680),
- c'_2 (CEET=0.680-0.763),
- c'_1 (CEET=0.763-0.880) and
- d' (CEET>0.880).

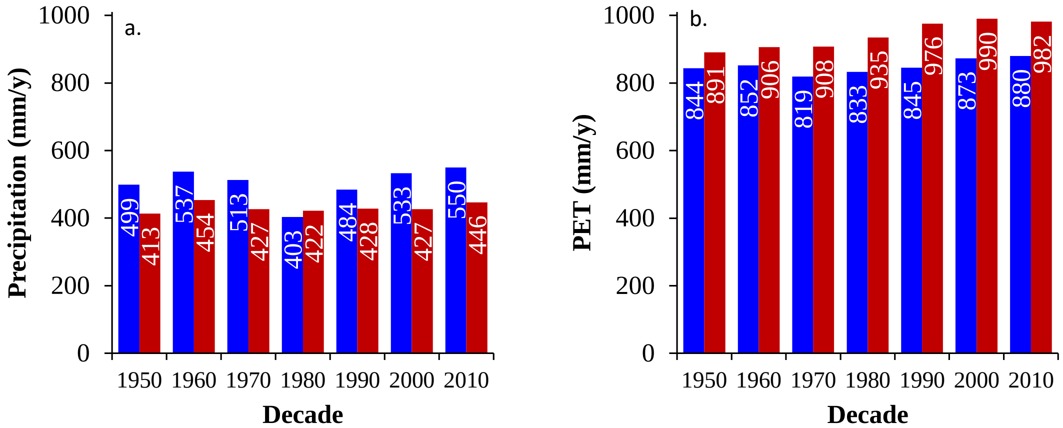
Finally, the changes of the ratio of the average annual decadal precipitation to the average annual precipitation of the total time-series (RPI) for both sites, were also investigated.

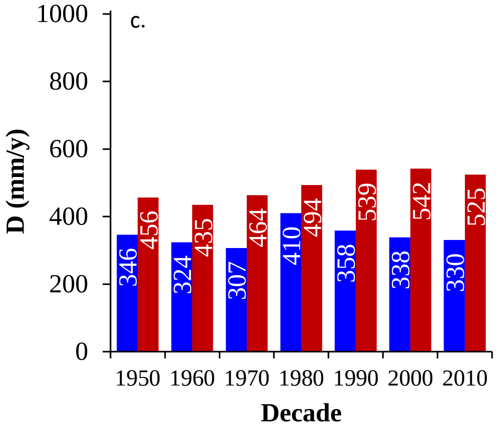
3. Results and Discussion

Considering the total dataset for the period 1955-2019 the climate in both the urban affected site in N. Filadelphia as well as the peri-urban site in Tatoi is semi-arid, mesothermal, with zero excess of water and moderate concentration of thermal efficiency in summer (climate types: D B'$_3$ d b'$_3$ and D B'$_2$ d b'$_3$, respectively). This general climate classification is in line with the findings of previous climate studies in Greece [11, 17], but it also shows important differences per decade as revealed by the decadal climate analysis. The climate types per decade based on Thornthwaite and Mather [13] classification are depicted in Table 1. The changes of the main water balance attributes in each site are different and graphically depicted in Figure 1.

Table 1
Climate types based on Thornthwaite and Mather (1955) classification.

Decade	Tatoi (peri-urban site)	N. Filadelphia (urban site)
1950's	D B'$_2$ d b'$_3$	D B'$_3$ d b'$_3$
1960's	D B'$_2$ d b'$_4$	D B'$_3$ d b'$_4$
1970's	D B'$_2$ d b'$_4$	D B'$_3$ d b'$_3$
1980's	D B'$_2$ d b'$_3$	D B'$_3$ d b'$_3$
1990's	D B'$_2$ d b'$_3$	D B'$_3$ d b'$_3$
2000's	D B'$_3$ d b'$_3$	D B'$_3$ d b'$_3$
2010's	D B'$_3$ d b'$_3$	D B'$_3$ d b'$_3$
1955-2019	D B'$_2$ d b'$_3$	D B'$_3$ d b'$_3$





d.

Decade	S (mm)	
	Tatoi	N. Filadelphia
1950	0	0
1960	10.28	0
1970	0	0
1980	0	0
1990	0	0
2000	0	0
2010	1.16	0

Figure 1: Decadal (1950's to 2010's) values of precipitation P, potential evapotranspiration PET, water deficit D, water surplus S for the sites of N. Philadelphia (red bars) and Tatoi (blue bars), based on Thornthwaite's water balance approach.

Precipitation in N. Filadelphia presents minor decadal changes, ranging from 413mm (1950's) to 454mm (1960's), whereas in Tatoi varies from 403mm (1980's) to 550mm (2010's). The 1980's decade for the Tatoi's station is the driest highly affecting the water balance of the site, since it is associated with moderate high PET (833mm). In general, at both sites the PET decadal values are high (varying from 891 mm in 1950's to 990 in 2000's for N. Filadelphia and from 819mm in 1970's to 880mm in 2010's for Tatoi) presented to increase the recent decades more rapidly in N. Filadelphia (trend slope 18.2 mm/decade) than in Tatoi (6.3mm/decade). These changes of PET in conjunction with the rather stable precipitation result in increased water deficits D that vary from 435 mm in 1960's to 542mm in 2000's for N. Filadelphia, with an increasing trend of about the same magnitude as in PET (17.7mm/decade). On the other hand, the less increasing rates of PET in Tatoi under the almost stable precipitation regime (with the exception of 1980's) result rather stable D values. In addition, in both sites the water excess (water surplus S) remains negligible or zero regardless of the decade. An exception can be identified for the 1960's and 2010's in Tatoi, when minor S values were recorded (10.28 and 1.16mm respectively) indicating a minor water surplus on an annual basis.

The impact of the above-mentioned changes and the relations between the water balance attributes (Precipitation, PET, D and S) in the two sites, highly affect important indices used in climate classification. The decadal values of the Thornthwaite's Aridity Index (AI), the potential evapotranspiration PET percentage of the drier trimester to the PET of the decade (CEET), the ratio of the average annual decadal precipitation to the average annual precipitation of the total time-series (RPI) and the Moisture Index (MI) for the sites of N. Filadelphia and Tatoi are presented in Figure 2.

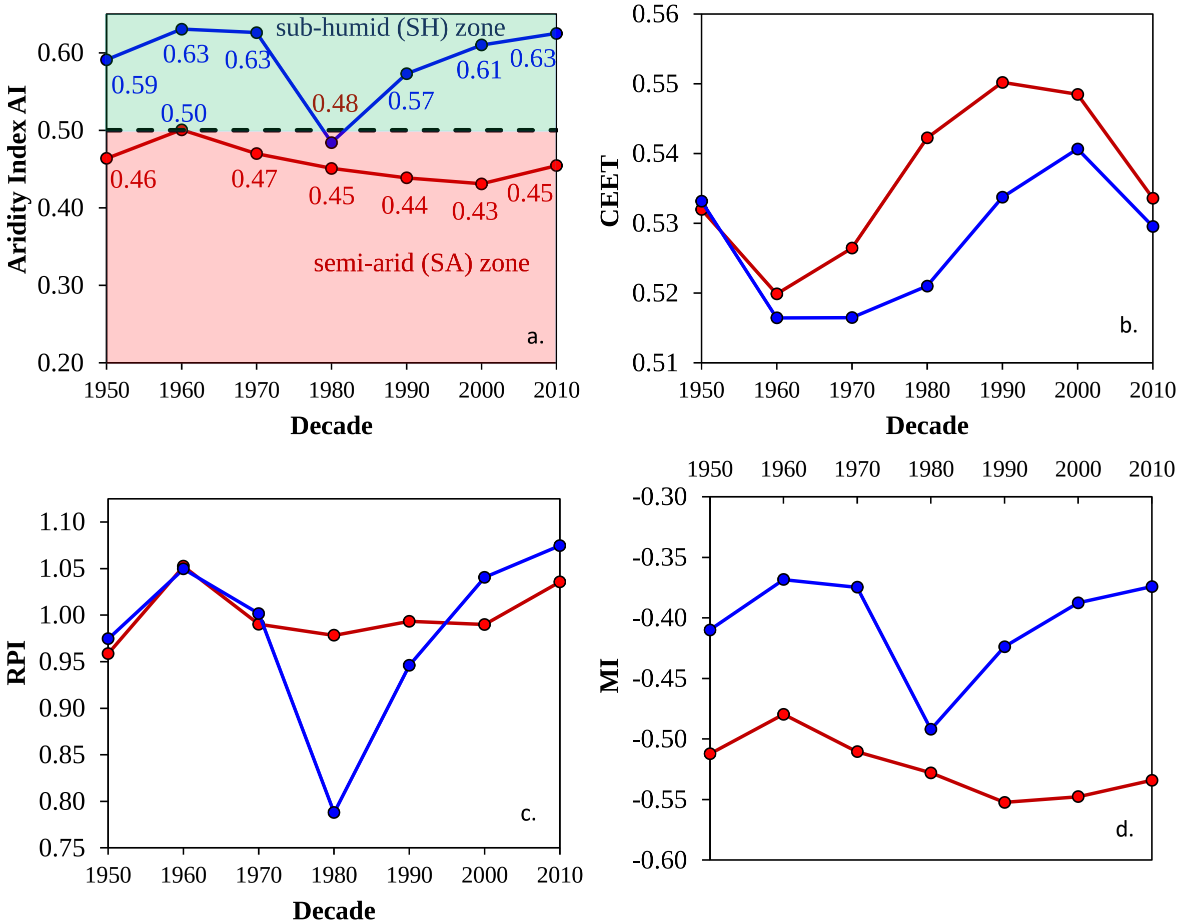


Figure 2: Graphical representation of the average decadal (1950s to 2010s) values of a) the Thornthwaite's Aridity Index (AI), b) the potential evapotranspiration PET percentage of the drier trimester to the PET of the decade (CEET), c) the ratio of the average annual decadal precipitation to the average annual precipitation of the total time-series (RPI) and d) the Moisture Index (MI) for the sites of N. Filadelphia (red lines) and Tatoi (blue line).

The combined effect of Precipitation and PET is incorporated in the values of AI. Its decadal values (varying between 0.43 in 2000's and 0.50 in 1960's) confirm the more arid conditions prevailing in the urban site of N. Filadelphia, which has a semi-arid (SA) climate, according to UNEP's [15] climate aridity classification compared to the semi-humid (SH) climate in the peri-urban site of Tatoi (AI range from 0.48 in 1980's to 063 in 1960's, 1970's and 2010's). However, it is worth noting that the climate in N. Filadelphia became more arid during the recent decades compared to the past with a persisting stable trend for the AI values. This is in line with similar studies in urban and forest environments in Greece that increasing aridity trends were also identified [4, 5, 7-11]. On the contrary, the sub-humid conditions in Tatoi are rather stable with time, with the exception of the 1980's decade, when the climate became semi-arid due to the diminished precipitation. For the specific decade the RPI values are reduced (0.79) indicating that in 1980's precipitation was by 21% lower than the long-term climatic average.

The CEET values indicate that the cumulative PET in summer is more than 50% of the annual total, indicating that the highest evapotranspiration rates and thus available water demands are recorded for summer. This fact introduces the need for irrigation support, especially in the urban environment, in order to sustain vegetation, considering also that summer precipitation consists on average only 7.7% in N. Filadelphia and 8.4% in Tatoi of their total annual precipitation.

4. Conclusions

The above patterns indicates that the region of Attica generally has small water inputs from precipitation that are mainly consumed for evapotranspiration, allowing almost zero surpluses. On the contrary, the water deficits are high with increasing trends in the recent decades compared to the past. The urban environment appears to face even more reduced water availability with less precipitation and higher evapotranspiration rates, compared to the peri-urban environment, resulting in higher water deficits with serious negative impacts on the urban green infrastructures in terms of plants' water requirements and their heat and water tolerance. This pattern is becoming even more hostile the recent decades compared to the past, whereas its changes are more rapid in the urban environment compared to the peri-urban.

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