Assessment of Streamflow Characteristics in a Watershed Using Flow Duration Curves and Hydrograph Analysis

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Keywords: Baseflow, Base Flow Index, Flow Duration Curves, Hydrograph Analysis.

Abstract: Assessment of streamflow characteristics can be considered as one of the most important evaluations that need to be performed in a watershed for water use planning, implementation of various restoration projects and the validation of its effectiveness. Out of the several available methods, flow duration curves (FDC) and hydrograph analysis can be considered as the most effective and simplest methods to assess the flow characteristics of a stream. The present study aims to evaluate the seasonal variations in the flow characteristics of one of the important rivers in central Kerala, India, the Meenachil river. The study was done by interpreting the Base Flow Index (BFI) values of seasonal FDCs and baseflow separation technique using data from 4 stream gauging stations in the catchment. As per the analysis, the river presented intermittent flows with variably gaining and losing river reach along its course. This intermittent nature of the stream was distinctly revealed through the full time FDCs sustaining flows for 47% of time on the upstream reaches to 72%, 62% and 78% progressing towards the downstream. The baseflow contribution to the stream was greatest during the SW monsoon season for all the stations, particularly station 4 recording a maximum of 40.8 cumecs. The BFI values calculated using both sliding interval method and FDC were comparable and presented a very good appraisal on the seasonal variations in the streamflow.

1 INTRODUCTION

The Flow-Duration Curve (FDC) is a cumulative frequency curve that shows the percentage of time specified discharges were met or exceeded in a particular period (Searcy, 2011). In a simpler definition, the flow-duration curve is a technique of displaying streamflow data by integrating the flow characteristics of a stream over a wide variety of discharge ranges into a single curve. Even though, the chronological sequence of flows is not reflected, the flow-duration curve is helpful in many studies (Singh, 2015) such as reservoir sedimentation(Strand and Pemberton 1982), water quality management (Searcy, 1959) etc. The curve is made to average the plotted points of specified discharges against the percent of the time they were equaled or surpassed, rather than the flow distribution within a single year. As a result, FDCs are excellent instruments for studying the catchment hydrological behavior and streamflow characteristics since their shape and slope indicate the at-site flow variability circumstances, as well as the catchment's flood-formation dynamics and low-flow features (Costa et.al., 2020). The flow-duration curve applies only to the period for which data is used to create the curve or to the period for which the curve is strictly altered. FDCs represent the sustainability of stream flows at a river cross-section over a specified time interval, commonly a day, week, or month (Vogal and Fennessey,1994; Smakhtin, 2001). Complete years of records should be utilized to generate a full-time flow-duration

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S., D., Chadaga, M., Lathashri, U., Salim, S., Jyoti, A. and Pant, S.
Assessment of Streamflow Characteristics in a Watershed Using Flow Duration Curves and Hydrograph Analysis.
DOI: 10.5220/0011907500003536
In *Proceedings of the 3rd International Symposium on Water, Ecology and Environment (ISWEE 2022)*, pages 90-95
ISBN: 978-989-758-639-2; ISSN: 2975-9439

curve; partial years should be avoided. However, seasonal data can also be used to generate seasonal flow-duration curves. The FDCs find its important application in hydro power potential studies (Hickox et.al., 1933; Barrows, 1943; Yizhi et.al.,2020). The upper end of FDCs is widely used in several studies related to flood assessment (Pettis, 1934; Beard, 1943; Gómez-Llanos et.al.,2018).

Stream hydrograph is a graphical representation of the total flow carried in a stream against the duration of streamflow. It is ideally considered to be representing three components of flow viz., direct runoff (which is the quick response of streamflow to precipitation), base flow (which is the contribution from the adjacent aquifer to the streamflow) and interflow which is following a shallow subsurface pathway to the stream (which is usually ignored assuming that it can be a part of either the surface runoff or the base flow). Baseflow separation technique is a very efficient tool which can be used to separate the baseflow from streamflow (Stewart, 2015). The clear distinction in the baseflow and direct runoff generation process is very evident in the shape and slope of the two recession curves generated. This justifies the requirement of separating the two components of streamflow (Hewlett, 1967). The watershed management practices could be dependent on the contribution of baseflow to the stream (Wondmyibza et.al., 2021). For example, overdraft from wells to meet the domestic and agricultural requirements, deterioration of water quality, pressure on surface and groundwater resources in drought prone areas etc. The baseflow contribution to the Meenachil river is yet unknown. Thus, the main objective of this paper is to interpret the BFI values generated using FDCs and hydrograph separation method to evaluate the seasonal variation in streamflow. This could be very effective in watershed management studies.

2 STUDY AREA AND DATA COLLECTION

Meenachil river originates from the Araikunnumudi at an elevation of approximately 1100 m above MSL and finds its way to the Vembanad lake. The Meenachil watershed, in the district of Kottayam, Kerala, India, experiences a tropical monsoon climate receiving excess rainfall during monsoon seasons and hot conditions in summer. The watershed receives rainfall primarily during the southwest and northeast monsoon seasons. The flooding of river during monsoon seasons is an annual event that occurs from June to September resulting in over-toping the banks and inundation of the low-lying lands. The Meenachil river extends 78 km long draining a total area of 1272km^2 , stretching between 9° 32’ to 9°50’ N latitudes and 76°29’ to 76°56’ E longitudes (Deepa et.al., 2022) (Figure 1). The Meenachil river is uniquely characterized by human settlement right from its origin at the Western ghats to its culmination in the Arabian sea.

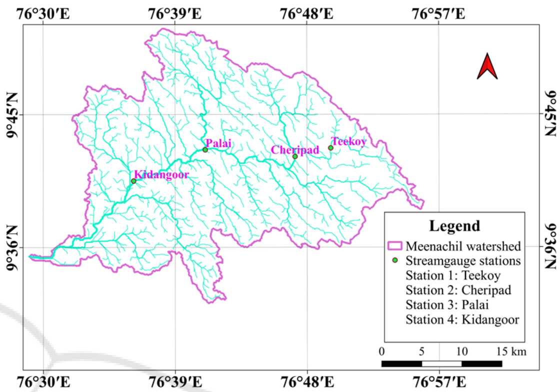

Figure 1: Meenachil watershed and location of stream gauge stations

Daily streamflow data was obtained from Irrigation Design and Research Board (IDRB), Trivandrum at four stations viz., station 1 (24 years), station 2 (22years), station 3 (23 years) and station 4 (25 years). The analysis was done for a period of only 17 years since comparison of results were required to be done for all the 4 stations using concurrent data. The years of missing data were excluded from the analysis.

3 METHODOLOGY

With the aim of presenting a cumulative perspective on the potential of the river to sustain its flows through baseflow contribution, the flow data were analysed using the flow duration curves (FDCs) and hydrograph separation technique. Using the FDC method and sliding interval method of hydrograph analysis, the baseflow index (BFI) was calculated and compared. For uniformity and easier comparison, these methods were applied considering concurrent time periods of data at four steam gauging stations viz., Station 1, Station 2, Station 3 and Station 4 (Figure 1) in the watershed. The concurrent time periods selected for the study spanned across four seasons viz., pre-monsoon from April to May, south-west(SW) monsoon from June to August, post monsoon in September and north-east(NE) monsoon from October to November.

The following essential points were taken into consideration for generating the flow duration curves and baseflow separation using the stream flow data.

(i) The period of data with no missing records, obtained from the Irrigation Design and Research Board (IDRB), Trivandrum were used in the study.

(ii) The physical conditions in the basin were ensured to be the same during the period of data collected.

4 RESULTS AND DISCUSSION

4.1 Seasonal Discharge Analysis

The streamflow data at the 4 gauging stations were carefully reviewed to record the maximum and minimum discharge values (Table 1).

Table 1: The minimum, average and maximum discharge recorded at the 4 stations.

Discharge Parameters in cumecs				
Season	Station	Minimum	Average	Maximum
Pre-Monsoon	1	0	1.05	59.48
	2	0	7.818	224.66
	3	0	8.324	181.36
	4	0	22.33	443.56
SW-Monsoon	1	0	11.81	211.72
	2	0	43.88	363.8
	3	0	43.85	826.82
	4	0	116.7	877.06
Post SW Monsoon	1	0	6.724	98.35
	2	4.16	33.34	395.02
	3	0	27.56	381.81
	4	2.23	78.16	679.83
NE Monsoon	1	0	3.999	207.63
	2	3.03	23.15	341.72
	3	0	25.57	392.95
	4	2.98	76.48	532.3
Post NE Monsoon	1	0	0.108	28.61
	2	0	2.755	54.38
	3	0	1.009	54.92
	4	0	3.707	107.3

It is emphasized that, the watershed is characterized to receive maximum discharge brought in during the SW monsoon season followed by the NE monsoon season. The flow detected during the pre-monsoon season (April- May) are due to the frequent intense showers, known as summer rains. However, the river fades away into virtually a barren land in the post monsoon season shortly after the NE monsoon rains.

4.2 Baseflow Separation

The under lying assumption in the base flow separation method is that base flow is equated to the groundwater contribution which in many cases need not be valid due to the unseen hydraulic connection of any other drainage systems. Also, it may be altered due to many anthropogenic influences like land use changes due to urbanization, surface water extraction or groundwater extraction for irrigation etc.

The hydrograph analysis generates an index namely the base flow index (BFI) which is expressed as the ratio of base flow to the total streamflow. The built-in tool, BFI +3.0, of HydroOffice 2012 software (Gregor, 2010a) was used in this analysis. The long-term statistics of BFI and baseflow contribution using the sliding interval method (Table 2) were calculated and compared for all the 4 seasons. This method also results in a rapid estimation of baseflow.

Table 2: Long term statistics of BFI and baseflow contribution (in cumecs) using sliding interval method.

Seasons	Indicator	Stations			
		1	2	3	4
Pre-Monsoon	BFI	0.07	0.29	0.13	0.16
	Base-flow	0.1	2.58	1.01	2.79
SW Monsoon	BFI	0.33	0.54	0.45	0.48
	Base-flow	2.79	17.4	12.9	40.8
Post SW Monsoon	BFI	0.21	0.61	0.5	0.59
	Base-flow	0.81	13.7	10.6	35
NE Monsoon	BFI	0.13	0.58	0.39	0.43
	Base-flow	0.29	10.1	8.99	24.3

The results of the baseflow analysis demonstrates that the baseflow index (BFI) is highest during the post monsoon season at all the stations expect station 1. Thus, in this season the flow in the river is sustained through strong baseflow contribution. The rainfall received during the SW monsoon season in the highland station 1, due to the steep terrain of the land, gets quickly drained off and thus was not available for groundwater recharge. Consequently, the subsequent post monsoon season displays lesser BFI portraying the lesser potential of the river to sustain its flows through baseflow contribution in the respective season. Moreover, at all the stations, the amount of baseflow contribution was highest during the SW monsoon season recording a maximum of 40.8 cumecs at station 4.

4.3 Flow Duration Curves

The percentage duration for which the river flow is recorded in the gauging station gives an idea about whether the stream can be classified as perennial, intermittent or ephemeral (Karen, 2008). Interpretation of FDC can provide a useful appraisal on the geological characteristics of the watershed (Winter, 2007). In this study, the potential of FDCs to understand the extent of baseflow contribution to sustain the stream flows in the river is demonstrated. The flow duration curves were plotted using the daily discharge values against percentage exceedance of flow on a semi-logarithmic scale for obtaining a clear display of the high and low flow values. The built-in tool, FDC 2.1, of HydroOffice 2012 software (Gregor, 2010b) was used in this analysis.

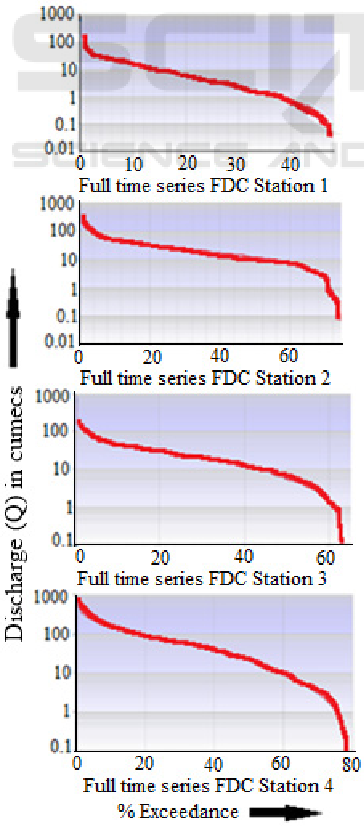

Figure 2: Full time series FDC (Station 1 to station 4).

The full time series for flow duration curve including zero discharge values recorded in the gauging stations of the watershed are presented in Figure 2. Station 1 carries discharge 47% of time which increases to 72%, 62% and 78% respectively towards downstream stations 2, 3 & 4. The percentage of time for which the river carries discharge from station 1 to station 4 reveals the type of hydraulic connection of the river reach with the underlying aquifer. It was found to be a variably gaining-losing river reach with dominated direct runoff flows interposed with base flow events from station 1 to 3 (Karen, 2008). However, from station 3 to 4, the river reach could be expected to change to a baseflow dominated river reach interposed with direct runoff events.

The generated FDCs exhibited a steep slope representing low or variable base flow contribution to the stream. Figure 3 and Figure 4 presents the flow duration curves across 4 different seasons viz., pre monsoon, SW monsoon, post monsoon and NE monsoon excluding the zero flow values. The seasonal FDCs so developed can be used to determine the Base flow Index values (BFI) which is the ratio of Q_{90}/Q_{50} (Nathen et.al.,1990) as presented in Table 3. High values of BFI index imply the potential of the river to sustain its flows for long duration (R Mohammed et.al., 2018). The results of the BFI using FDC method were comparable with the results of sliding interval method of hydrograph separation.

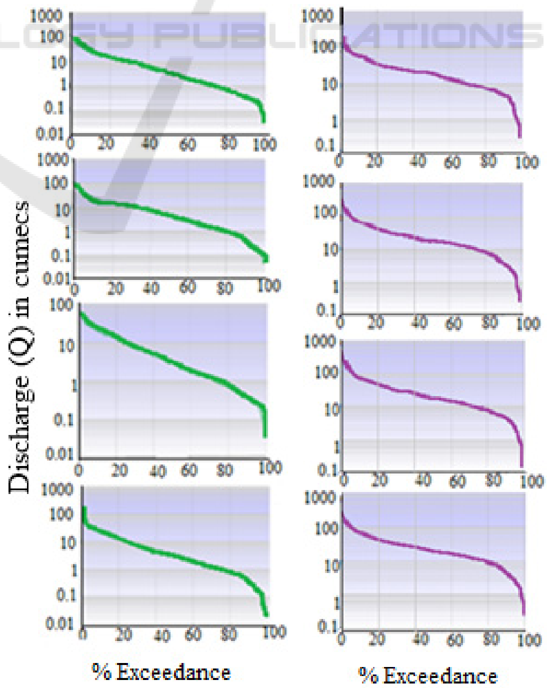

Figure 3: FDC@ station 1 and 2 across 4 seasons.

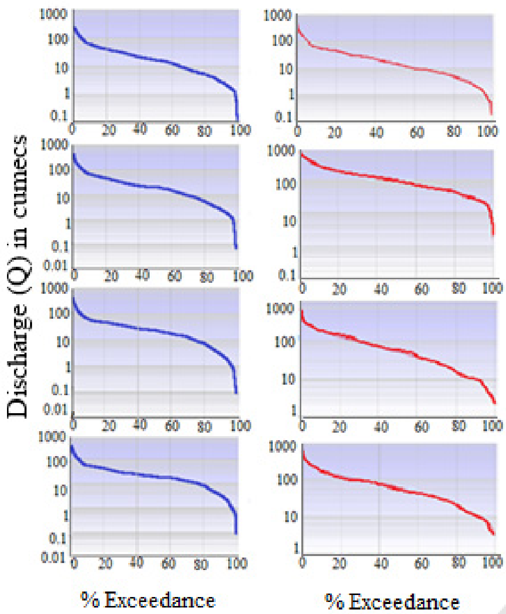

Figure 4: FDC@ station 3 and 4 across 4 seasons.

Table 3: Seasonal BFI (Q_{90}/Q_{50}) from upstream to downstream stations.

Station	Season	Q_{90}	Q_{50}	BFI
Station 1	Pre-Monsoon	0.28	3.34	0.084
	SW Monsoon	0.48	4.17	0.115
	Post SW Monsoon	0.36	3.14	0.115
	NE Monsoon	0.32	3.19	0.1
Station 2	Pre-Monsoon	3.63	17.1	0.212
	SW Monsoon	3.52	18.91	0.186
	Post SW Monsoon	0.3	17.37	0.017
	NE Monsoon	4.19	20.15	0.208
Station 3	Pre-Monsoon	2.33	16.34	0.143
	SW Monsoon	2.3	18.9	0.122
	Post SW Monsoon	2.67	22.57	0.118
	NE Monsoon	3	20.1	0.149
Station 4	Pre-Monsoon	2.31	13.8	0.167
	SW Monsoon	26.2	84.58	0.31
	Post SW Monsoon	8.78	46.14	0.19
	NE Monsoon	10.94	55	0.199

5 CONCLUSIONS

The present study on assessment of the streamflow characteristics and the potential of the river to sustain its flows throughout the year was done using flow duration curves and hydrograph analysis. The flow regime in the watershed was evaluated to be a variability gaining and losing reach across the seasons. The flow duration curve presenting the percentage duration in a year for which the river could sustain its flow along its course varied from 47% of time on the upstream station 1 to 72%, 62% and 78% progressing towards downstream station 2, 3 & 4 respectively. This clearly proved the intermittent nature of the river with alternatively gaining and losing river reach dominated with direct runoff on the upstream and baseflow events towards the downstream. The BFI values (Q_{90}/Q_{50}) was found to be maximum at station 2 for pre monsoon and NE monsoon seasons and station 4 for SW and post SW Monsoon seasons. Thus, the potential of the river to sustain its flows upstream of station 2 and station 4 was also evident.

The shape of the FDC, particularly the lower end, graphs the general characteristics of the shallow aquifer. The steep slope exhibited by the curves in the pre-monsoon and NE monsoon season in the gauging station 1 represents poor groundwater contribution to the stream. This is due to its location in the highland region possessing considerably low groundwater potential. However, the curve remains horizontal for the SW and post monsoon seasons at the gauging station 4. This can be due to high groundwater contribution to the stream from the underlying aquifers. A detailed analysis of the discharge data using FDCs and the hydrograph analysis perceived the greatest contribution to the stream through baseflow in the SW and post monsoon seasons. However, station 4 recorded the maximum of 40.8 cumecs in the SW monsoon season. The baseflow index (BFI) calculated using the sliding interval method yielded values increasing from station 1 to station 4, across all four seasons. These values were observed to be comparable with the BFI values generated using FDC method. Thus, the interpretation of FDC curves and results of baseflow analysis generated a good insight into streamflow characteristics and the potential of the river to sustain its flows through baseflow contribution.

Further studies are required in the watershed for thorough understanding of surface water and groundwater resource problems. The study of surface water groundwater interaction, the impact of groundwater contribution to the stream under climate change etc can be listed as few among the important watershed management studies. The studies listed above can prove to be very useful in formulating the storage-outflow relationship between aquifer and stream. It can also benefit in water resource planning and development and for adopting watershed management practices specifically to the Meenachil watershed.

ACKNOWLEDGEMENTS

Authors would like to thank Manipal Academy of Higher Education, Dubai for supporting the study by providing the Research Grant for data collection. Authors would also like to thank Irrigation Design and Research Board (IDRB), Trivandrum for providing the streamflow data.

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