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Analysis of Regional Flow Duration Curve for the Rainwater Harvesting Systems in Different Climate of Iran

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Abstract

Water harvesting has been widely applied in different climate zones, proving to be a valuable approach to sustainable water resource management. Regional estimates of the potential of water harvesting are generally based on purely hydrological assessments and mostly neglect the flow duration dimension of river. The purpose of this study was to analyze the indices to be extracted from flow duration curve (FDC) in the different climate areas. In this research, the basins in each climatic region were first separated by intersecting of climatic map and the border map of the basins. Then, 30 hydrometric stations with the common period (1976-2017) in two climate areas were selected. FDC using daily stream flow data were extracted by Hydro Office - software (2015) and then indices of Q_2, Q_5, Q_{10}, Q_{15}, Q_{20}, Q_{50}, Q_{75}, and Q_{90} were computed. The slope of FDC were computed and finally the results were analyzed and interpreted. The results showed that variation of FDC slope in the basins of humid area was in the interval of (0 to 39%) and in the semi-humid climate in the interval (0 to 48%). In humid basins, the minimum difference between the indices were related to the beginning and end of FDC (Q_2 and Q_{90}) and the maximum changes were in the middle part of FDC (Q_{15} and Q_{20}).

Key words: Base flow, Climate, Flow duration curve, Rain water catchment system

1. Introduction:

In recent years, Iran is facing a number of challenges including water scarcity, land degradation, poor agriculture and livestock productivity. With increasing population pressure, changing dietary habits and economic development, per capita resource availability is rapidly decreasing. Changing climatic conditions are adding to water resource scarcity and uncertainty (Ferrant et al., 2014).

Rainwater harvesting or the collection of rainwater in a proper way, can be a permanent solution to the problem of water crisis in different parts of the world. Recognizing and analyzing of sustainable water resources is a prerequisite for plans related to rainwater harvesting systems. Rainwater catchment systems include three parts, basin area, transfer system and storage tank. Regarding the rainwater catchment, which is the main part of this system, it is necessary to know the potential of the area in terms of the presence of adequate precipitation, flow duration and natural and man-made surfaces, which can be used for rainwater harvesting (Rashidi-Mehrabadi, 2013). The issue of recognizing and analyzing water resources capacities, in order to provide basic information for integrated water management, was raised for the first time at the United Nations environment conference in Stockholm (Meire et al., 2008). Then it was seriously followed in the water resources conference held in Dublin in 1992 (Porto and Porto. 2008). Knowledge and analysis of water resources is one of the key necessities to achieve comprehensive watershed management. In the last two decades, several researches have been carried out to identify the components of hydrology and to implement rainwater harvesting projects. A GIS-based approach for identifying potential sites for rainwater harvesting was done by Adham et al. (2018). Results showed that socioeconomic criteria, however, can also be important for rain water harvesting and should be studied in more detail and seriously taken into account. The investigation of rainfall and discharge trends in the Aras basin located in the northwest of Iran was carried out by Dastourani and Yazdanpanah-qaraei (2020) in order to provide the necessary information for decision-making and support systems for plans related to rain water harvesting systems. The results of the trend analysis showed that there was an increase in rainfall in two rain fall stations and no trend in the rest, and a decrease trend in six hydrometric stations and no trend in three hydrometric stations. With the same point of view, the investigation of the runoff production capacity from the rocky surfaces of the basin for supplementary irrigation in the Haftbagh - Alavi basin of Kerman, Iran, was carried out by Mirtaheri et al. (2020). The results showed that by harvesting only 10% of the cumulative losses of four rocky sub-basins, 8.055 million cubic meters of water can be collected and water can be provided for supplementary irrigation of about 16110 hectares of gardens. The evaluation of the impact of land use changes on the surface water quality in the Mahabadchai basin of Iran was done by Akbari et al. (2020). The results showed that it is necessary to investigate this issue to provide basic data for water supply plans from rain water catchment systems.

Flow duration curve (FDC) is a way of organizing the discharge data of a river or a stream in a graphical appearance that gives an estimation of the fraction of the time at which the flow rate equals or exceeds some value of interest (Kamran et al., 2020). The shape and general interpretation of each FDC depends on the hydrological and physiographical characteristics and statistical period. And also shape of FDC is an indicator of hydrological conditions of basin, and the slope of curve at any moment shows the flow rate at that moment. If the slope of the low flow part of FDC is small, the low flow is stable and its steeper slope indicates variable and low base flow (Zheng et al. (2007). Application of FDC has been spread in various aspects of hydrology and related sciences, including the research related to river pollution management and sedimentation and erosion conducted by various researchers such as Benasik and Hejdak (2013) and Rosburg (2015). Among other applications of FDC is its use in water resources planning, including drinking water supply, agriculture, fish farming and research related to ecosystem protection, low flow studies and hydroelectric energy production and water systems design (Langat et al. (2019). The use of FDC shape index has been used by Yuko and Sivaplan (2011) and Chen et al. (2012) to investigate the effect of climate on the flow and to interpret hydrological response of the basin. Using the FDC shape index to analyze the hydrological response and climatic effects on surface water was carried out by Chouaib et al. (2018) in 73 basins of the eastern United States. Their results showed that in the basins with a high FDC slope, the contribution of subsurface flows in the river flow was higher than in other basins where the FDC slope was lower.

In summarizing the literature review, it should be mentioned that rainwater harvesting plans, require attention to sustainable water resources as a road map and a prerequisite for other studies related to water resources. Therefore, the purpose of this research was to investigate and analyze FDC indices in the basins of humid and semi-humid climatic regions of Iran.

2. Materials and methods

2.1. Study Area

The study area is located in the seventh-order basins of Iran and in two humid and semi-humid climatic regions. The basins of the humid climate region, which have been selected by intersecting the climate maps and basin boundaries; It is mainly located within the boundaries of Mazandaran, Kurdistan, Chaharmahal-Bakhtiari, Kohgiluyeh and Boyer Ahmad provinces. The minimum height of basins were six meters above sea level and corresponds to the basin with code 26221 and the maximum height was 3067 meters corresponding to the basin with code 14284 and the area was 79 to 4116 (km^2). The average slope range of the basins were from 0.4 to 49.9%. The selected basins of the semi-humid climatic zone were from the Lorestan, Kurdistan, Kermanshah and Mazandaran provinces. It has a minimum height of 88 meters above the sea level corresponding to the basin with the code 15421 and a maximum of 2823 meters corresponding to the basin with the code 232322 and the area of the studied basins in this climate was from 108 to 2316 square kilometers and the average slope of the basins is from 1.04 to 46.86%. The general characteristics of the studied basins from each climatic region were presented in Table (1) and study area in Figure (1).

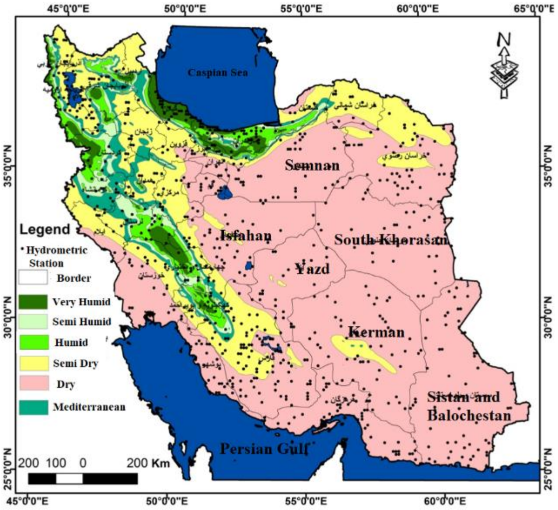

Fig.1. Study area

Table 1. Basin characteristics of the study area

Descriptive statistics / Parameter	H (m)	A (km^2)	RL (km)	S %	P (mm)	NR
Average	1945	847	384	26	625	52.86
Maximum	3067	4117	1100	50	1078	72.57
Minimum	6	80	60	0	308	34.54

H: height; A: area; RL: main river length; S%; basin slope; p: averages of annual rainfall; NR: number of rainy days

2.2. Methodology

In this research, the basins in each climatic region were first separated by intersecting of climatic map and the border map of the basins. Then, 30 hydrometric stations with the common period (1976-2017) in two climate areas were selected. FDC using daily stream flow data were extracted by Hydro Office - software (2015) and then indices of Q_2, Q_5, Q_{10}, Q_{15}, Q_{20}, Q_{50}, Q_{75}, and Q_{90} were computed. Using programming in MATLAB, the slope of the distance from Q_{33} to Q_{66} was calculated as an index of FDC shape. Then, using the annual time series of the FDC slope, the trend of changes in FDC slope was drawn and the exceedence value equivalent to the zero slope of FDC was considered as the amount of sustainable water. The normalised FDC indices were calculated in relation to Q_{50} and finally the results were analyzed and interpreted.

2.2.1. Slope of flow duration curve (S_{fdc})

The FDC was calculated using the daily stream flow data and the slope of FDC using equation (1) as a representative of the slope of FDC was computed.

$$S_{fdc} = \frac{LogQ_{33} - LogQ_{66}}{0.66 - 0.33} \qquad (1)$$

where Q_{33} and Q_{66} are flow rates equivalent to 33% and 66% exceeding value (%) and S_{fdc} is the slope of FDC.

3. Results and discussion

After drawing the FDC of all basins, the percentages Q_2, Q_5, Q_{10}, Q_{15}, Q_{20}, Q_{50}, Q_{75}, Q_{90} were extracted. Table (2) shows the values of the minimum, maximum and average FDC percentiles of the basins located in each climatic region.

Table 2. The minimum, maximum and average exceedance value of FDC in the selected basins

Q_{90}	Q_{75}	Q_{50}	Q_{20}	Q_{15}	Q_{10}	Q_5	Q_2	Exceedance value (m^3/s) / Descriptive statistics	Climate
49	60	64	76	84	91	91	90	Average	Humid
74	78	86	97	97	97	98	98	Maximum	
30	26	29	30	28	40	51	55	Minimum	
50	62	68	79	90	94	92	92	Average	Semi Humid
74	81	86	98	98	98	98	98	Maximum	
23	41	38	30	63	63	64	53	Minimum	

In the selected basins of humid climate zone, the least difference between the indices were related to the beginning and end part of FDC (Q_2 and Q_{90}) and the maximum fluctuation and changes were related to the middle part of FDC (Q_{15} and Q_{20}). In the semi-humid climate basins, the minimum difference between the indices were similar to the humid area, corresponding to the beginning and end of FDC (Q_2 and Q_{90}), and the maximum fluctuation and changes were related to the middle part of FDC (Q_{20}). An example of FDC of selected basins in humid and semi-humid climatic regions were presented in Figure (2).

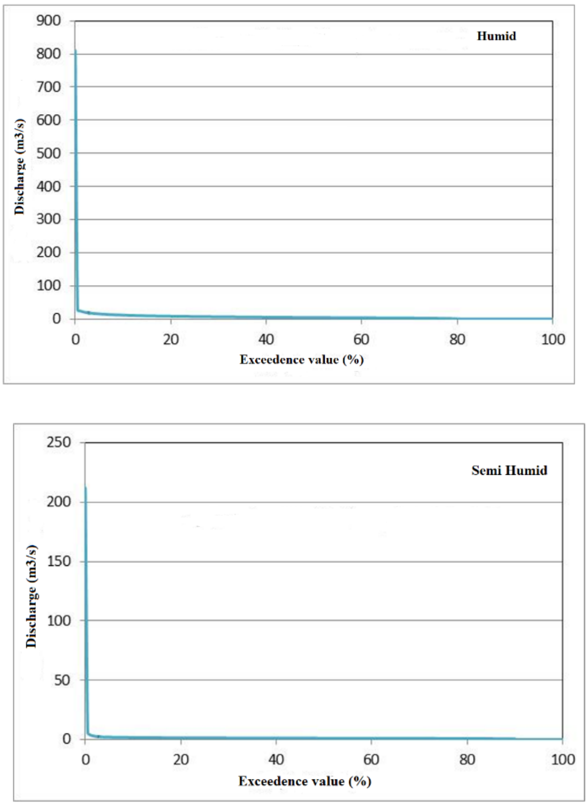

Fig. 2. An example of the flow duration curve of basins in humid and semi-humid climate basins

Investigating the turning points of FDC in the basins of both climate zones showed that the first inflection point of FDC in basins of both climates, occurred in the upper part of FDC and passing from Q_2 to Q_5, which was affected by the hydrological conditions of the basins (Table 2). The second important inflection point of FDC was shown between Q_{20} and Q_{50}. This second turning point represents the transition from flooding to normal conditions. Of course, the slope of the curve at the breaking point in each basin was different according to the climatic region and the physical and hydrological characteristics governing the basins. In this research, FDC slope of the basins in humid and semi-humid climatic regions have almost equal and similar conditions. The most important turning point of FDC after which water scarcity conditions were observed was the last turning point, which generally occurs from Q_{50} to Q_{75}, but in selected basins from the humid and semi-humid region, the slope changes gradually and the major failure occurs from Q_{75} to Q_{90}. The last turning point where the slope of FDC was almost equal to zero considered as a representative of groundwater contribution to surface water. Changes of FDC Slope in humid climates fluctuate from (0 to 45%) and in semi-humid climates, it ranges from (0 to 48%). In humid and semi-humid basins, it was almost similar and includes about 40% of the year. The most changes in FDC slope in the basins of the two climates were similar and within the range of zero to 20%, and the difference was only in the upper part of FDC, which was related to flood conditions. The FDC slope, between Q_{33} and Q_{66} during the research period, was calculated and the slope duration curve (SDC) values were prepared as a time series and by adapting FDC drawing method. In order to provide a comprehensive view of all selected basins, the average shape index, calculated and general diagram of SDC related to the humid and semi-humid climatic region were presented in Figure (3 and 4). In the semi-humid region (Figure 3), the shape index of SDC ranges from 47 to 15% with an exceeding value of 5% and 15% to zero slope with an exceeding value of 5 to 99%. The gentle slope range of 0 to 15% indicates the wide range of sustainable water access, in order to be used in the plans related to the water resource managements in this climatic region.

In the basins of the humid region (Figure 4), the shape index ranges from a slope of 37 to 15% with an exceedance value of 5% and a curve slope of 15% to zero with an exceeding value of 5 to 99%. In order to provide logical and scientific interpretation conditions in the selected basins, the FDC indices were calculated in relation to the Q_{50} and the results were presented in table (3).

As can be seen, in the basins of the semi-humid climate region, the percentage of deviation from the normal index(Q_{50}) in upper part of FDC was approximately 42% in Q_{10}, and the percentage of deviation from the normal index (Q_{50}) in the low flow part of FDC (Q_{75} and Q_{95}) was 8 and 26 %. These values show the reliability of sustainable water availability in the basins of semi humid climatic region.

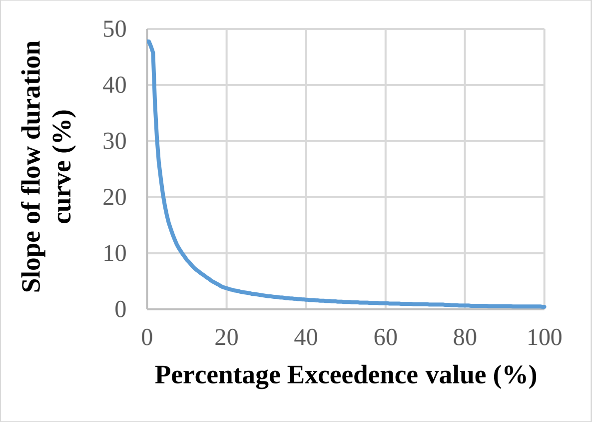

Fig. 3. Changes in the slope of FDC of selected basins from semi-humid climate

In the basins of the humid climate region, the average deviation of the indicators of upper part of FDC (Q_5 to Q_{20}) from the normal index (Q_{50}) was up to 45%. This was 6% in the indicators of low flow part of FDC (Q_{75} and Q_{95}) and 24% in (Q_{95}).

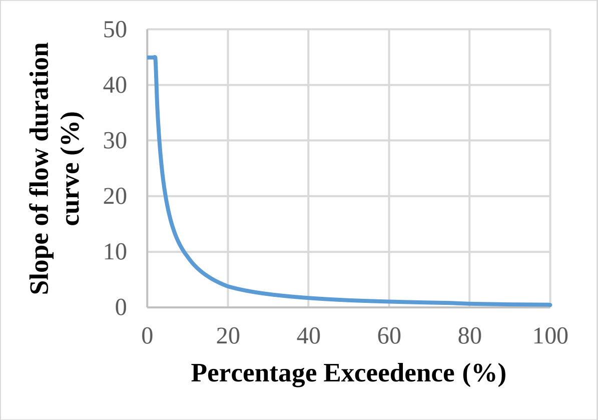

Fig. 4. Changes in the slope of FDC of selected basins from the humid climate

The comparison of FDC indices in selected basins from two climatic regions showed that the average deviation of the FDC indices from the normal index (Q_{50}) was close to each other in both regions and the conditions of access to sustainable water were similar in both regions.

Table 3. Minimum, maximum and average FDC indices relation to normal exceedance value ($Q_{(x)}/Q_{50}$)

Climate	Q_{Final}	Q_{95}/Q_{50}	Q_{75}/Q_{50}	Q_{20}/Q_{50}	Q_{15}/Q_{50}	Q_{10}/Q_{50}	Q_5/Q_{50}	Descriptive statistics
Semi humid	68	0.74	0.92	1.16	1.36	1.42	1.39	Average
	84	1.03	1.16	1.45	2.21	2.53	2.33	Maximum
	40	0.45	0.73	0.78	1.08	1.09	1.06	Minimum
Humid	66	0.76	0.94	1.18	1.32	1.45	1.45	Average
	84	1.33	1.09	1.31	1.66	2.54	2.42	Maximum
	30	0.62	0.82	1.01	0.95	1.09	1.08	Minimum

Considering that the duration of the base flow availability can be used as a prerequisite for water-related projects. In order to ensure the amount of base flow in water resource management plans of the basin, the exceeding value at the point of zero slope of FDC (Q_{Final}) by calculating the FDC slope and estimating the flow rate at the opposite point of the zero slope was obtained and the values presented in table (3). The probability range of base flow availability in semi-humid areas were from 40 to 84% of the year and for humid areas from 30 to 84%.

4. Conclusion

For the comprehensive water resources management, we need a comprehensive look at the various components of water resources. Regarding the design and site selection of rain water harvesting systems, it is necessary to pay attention to the sustainable water resource indicators through the recognition and analysis of FDC. Therefore, knowing the changes in the FDC slope and the turning points of FDC in different climates, helps to interpret the hydrological conditions of the basins more accurately.

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6. Disclosure statement

No potential conflict of interest was reported by the authors

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