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Low-Flow Indices in Sub Catchments of Caspian, Iran

Rahim Kazemi[a*] and Bagher Ghermezcheshme[b]

[a&b]Soil Conservation and Watershed Management Research Institute, Agricultural Research, Education and Extension Organization, Tehran, Iran

[*]Corresponding Author, E-mail address: Kazemi@alumni.itc.nl
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Abstract

Low flows are one of the most important hydrological parameters required for quantitative and qualitative analysis of watersheds and play an important role in water resources engineering and management. In this study, 9 low flow indices including mean annual 3,7,15,30, days average minimum flow, flow duration curve indices (FDC) and exceeded 95, 90, 75 and 25% of the time respectively, and base flow index (BFI) were used. Daily stream flow of 20 hydrometric stations with a period of 30 years were used. BFI was extracted using One-parameter recursive digital filter algorithm and FDC indices were determined by plotting FDC. Then, the relationships between selected indices were analyzed. The results showed that there was a good correlation between base flow and FDC indices with a coefficient of determination above 68%. MAM3, MAM7 and MAM30 indices had a good correlation with a coefficient of determination higher than 0.90 and a suitable standard error for FDC indices that can be used for regional analysis of low flow. The MAM30 low flow showed the minimum standard error and the maximum coefficient of determination with FDC indices. The MAM15 low flow index had no correlation with FDC indices and not recommended for regional analysis of low flow in the research area.

Keywords: Base flow index, FDC, Hydrograph analysis, Iran

1. Introduction

The development of management strategies to minimize the negative impacts of droughts relies on our ability to predict droughts at different time scales. (Mirza, 2010). In recent years, many attempts have been made to find a new approach to estimating and predicting low flow indicators, including the following.

Worland et al. (2018) compared the ability of eight machine-learning models at 224 unregulated sites in South Carolina, Georgia, and Alabama, USA. They concluded that The machine-learning models produced substantially lower cross validation errors compared to the baseline models. Sapac et al. (2020) assessed the consistency of various low-flow indices at 12 water stations in the Ljubljanica river catchment, Slovenia. They concluded that Although it shows consistency between low-flow indices, some variations demonstrate that in case of hydrologically and geologically heterogeneous catchments, an analysis of several low-flow indices is needed in order to obtain a holistic overview of low-flow conditions and to avoid wrong decisions in water resources management due to inappropriate consideration of low-flow characteristics. Whitaker et al. (2022) proposed a convenient procedure to low flow analysis that is applied to 29 basins in eastern Japan to develop linear regression models. Result showed high R^2 values of 0.705 and 0.717 for the $Q7_{10}$ and $Q97_{10}$ models, respectively.

The following can be mentioned from the cases of research conducted in Iran. Eslamian et al. (2004) used the multivariate regression method based on the physiographic factors of the basin to estimate the MAM7 with a return period of 2, 5, 10, and 20 years in the Mazandaran watershed. They concluded that this method has good accuracy for the 18 homogeneous basins identified in the region, for the mentioned return periods. Nosrati et al. (2004) zoned the values of Q7,10 as an index for drought studies in Karkheh watershed. The results showed that low flow and drought have spread throughout the region. Noori Gheidari and Hosseinitodashki (2014) with a new approach to modeling low flow in the Urmia watershed and introduced the probabilistic distribution to describe water deficit indices.

Numerous cases of application of low flow indices that were conducted in the field of water resources, showed the importance and value of these indicators for various analyzes. In this study, considering the importance of the relationships between these indicators, an attempt has been made to study and analyze correlational relations in sub catchments of Caspian basin, Iran.

2. Materials and Methods

3.1. Study area

The study area is located between latitude 36°11' - 38°48' east and longitude 48°48'- 53°13' north and includes twenty catchments located in the coastal strip of the Caspian Sea (Figure 1). Dominant land use is forest, rangeland and agriculture. The study area was affected by the Caspian and Mediterranean climate. Most of the annual rainfall in the study period with the amount of 1131 mm belongs to the Khutbesara catchment and the minimum was related to the Nor catchment with 505 mm. Carbonate formations have a suitable coverage and its maximum coverage belongs to the Samush Heratbar catchment with a surface coverage of 75%. Hard non-carbonate formations mainly include sandstone, shale, andesite and basaltic tuffs and its maximum surface coverage is in Choobar catchment (Bala Mahalla) with 99% of surface cover. The Quaternary formations mainly include accumulation terraces, young and old alluvial fans and wind-blown sand deposits (Kazemi and Eslami, 2013). The basic characteristics of the study areas were presented in Table 1.

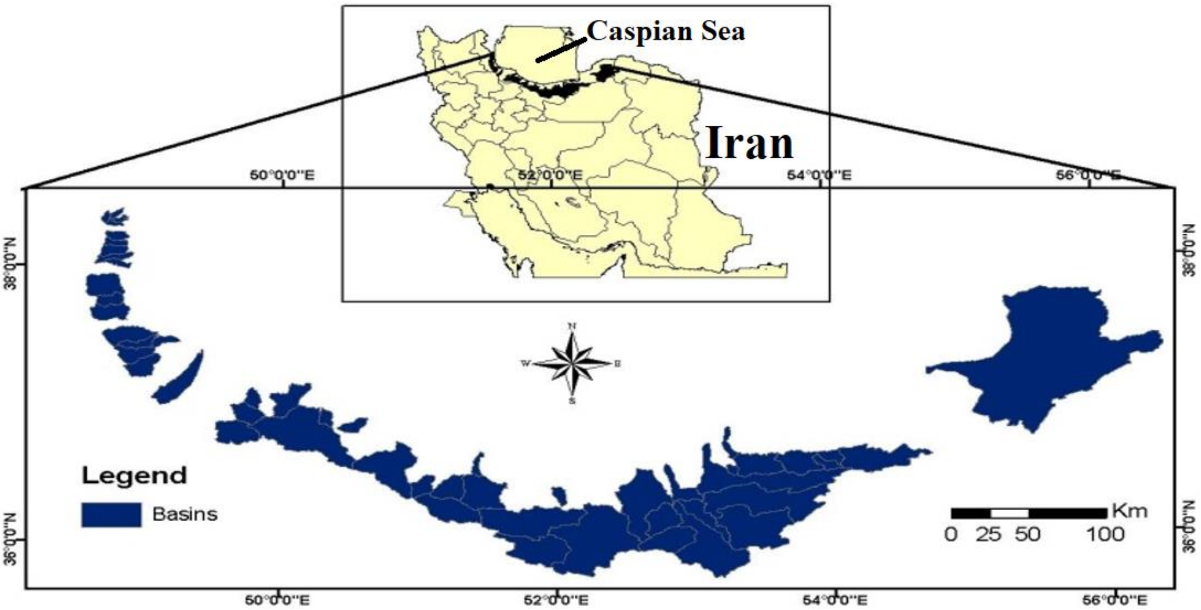

Fig. 1. Study area

Table 1. Basic characteristics of the studied catchments

Hydrometric station Code	Catchment Name	latitude	Longitude	average altitude (m)	Average annual rainfall (mm)	BFI
12-025	Rig Cheshme Tajan	36,22	53, 10	2041	680	0.61
13-019	Suleiman Tangeh-Tajan	36,15	53,13	2095	657	0.52
14-005	Shirgah (Kasilian)	36, 17	52,53	1831	979	0.59
14-011(15-001)	Babolrud (Quran Talar)	36,16	52,48	1692	971	0.51
15-015	Nor	36,11	52,11	2722	505	0.51
15-017	Kore Sang	36,16	52,22	2989	536	0.50
16-003	Lavich	36,35	52,54	1965	659	0.57
16-021	Chalous	36,30	51,20	2378	544	0.50
16-023	Sardabrood (Kelardasht)	36,29	51,07	3030	625	0.63
16-041	Cheshmeh Gileh (Heratbar)	36,46	50,55	2410	620	0.56
16-059	Samush (Heratbar)	3759	50,17	1866	1019	0.65
17-045	Totkain	36,53	49,31	1440	427	0.69
17-051	Zilaki (Shahre Bijar)	37,00	49,38	1413	727	0.59
17-055	Desham (Pashaki)	37,01	49,48	735	1080	0.56
18-019 (18-09)	Rudbarsara-Chafrud	37,27	49,05	1364	1110	0.54
18-021	Shafa rud(Ponel)	37,32	49,05	1504	1074	0.60
18-029	Karkanrud (Gorganrud)	37,48	48,48	1639	845	0.60
18-035	Shirabad	38,48	48,58	1551	942	0.59
18-039	Choobar Bala Mahale)	38,12	48,51	1203	1015	0.50
18-055	Khotbe sara	38,03	48,53	1190	1131	0.63

3.2. Methodology

The daily stream flow data of hydrometric stations, twenty stations with appropriate statistics and a common period of 1365-1395 were selected. Then 9 low flow indices including mean annual 3,7,15,30, days average minimum flow(MAM); flow duration curve indices (FDCI) and exceeded 95, 90, 75 and 25% of the time respectively were determined by plotting FDC. Base flow index (BFI) was extracted using One-parameter recursive digital filter algorithm using Hydro Office, 2015 software. Then correlation relationships were extracted, investigated and analyzed using SPSS software.

3.3. Base flow Separation

Separation of the base stream can be done during the flow hydrograph separation process, by identifying the starting and ending point of the direct runoff. The starting point is the point at which the current rises, and the end point is when the logarithm of the descending branch turns into a straight line with respect to time. Various methods have been developed to separate the flow hydrograph and have been used in previous research. In this research, flow hydrograph separation and basic flow extraction and calculation of the relevant index were performed using a one-parameter digital filter algorithm and after reviewing and preparing daily flow data using 2010 Hydro office software. Using the graphical display of the software and using different values of the parameter and its calibration, the required optimal parameter value was determined and the water level and the relevant index were extracted.

Many hydrograph separation techniques have been applied to identification of the different flow components of the total flow. The components are thought to represent different flow paths in the catchment, each characterized by different flow has traditionally been separated into a flow that originates from overland (direct), unsaturated (thorough flow) and saturated (groundwater) flow. In their review Nathan & McMahon (1992) distinguish between methods for continuous separation of the different components of the flow (Tallaksen & van Lannen, 2004).

Various methods have been developed to separate hydrographs and have been used in previous research. In this research, hydrograph separation and base flow calculation were performed using one-parameter recursive digital filters and Hydro office 2015 software.

3.3.1. Recursive digital filter

The recursive digital filters are routine tools in signal analysis and processing, were used to remove the high-frequency quick flow signal to derive the low-frequency base flow signal. The single-parameter digital filter with the following algorithm was first introduced by Chapman and Maxwell (1996).

$$q = \frac{q}{2-k} q_{b(i-1)} + \frac{1-k}{2-k} q_{(i)} \tag{1}$$

$q_{b(i)} \leq q_{(i)}$ Applied as a single pass through the data; $q_{(i)}$ is the original streamflow for the i^{th} sampling instant; $q_{b(i)}$ is the filtered baseflow response for the i^{th} sampling instant; $q_{b(i-1)}$ is the filtered base flow response for the previous sampling instant to i; k is the filter parameter given by the recession constant.

The above algorithm has a high sensitivity to the parameters and due to its ability to automate, it has no problems due to inconsistency of results by different specialists. And due to the ability to apply multiple times on the data, the resulting curve is smoothed and the possible error is reduced. Figure 2 is an example of a hydrograph separation curve.

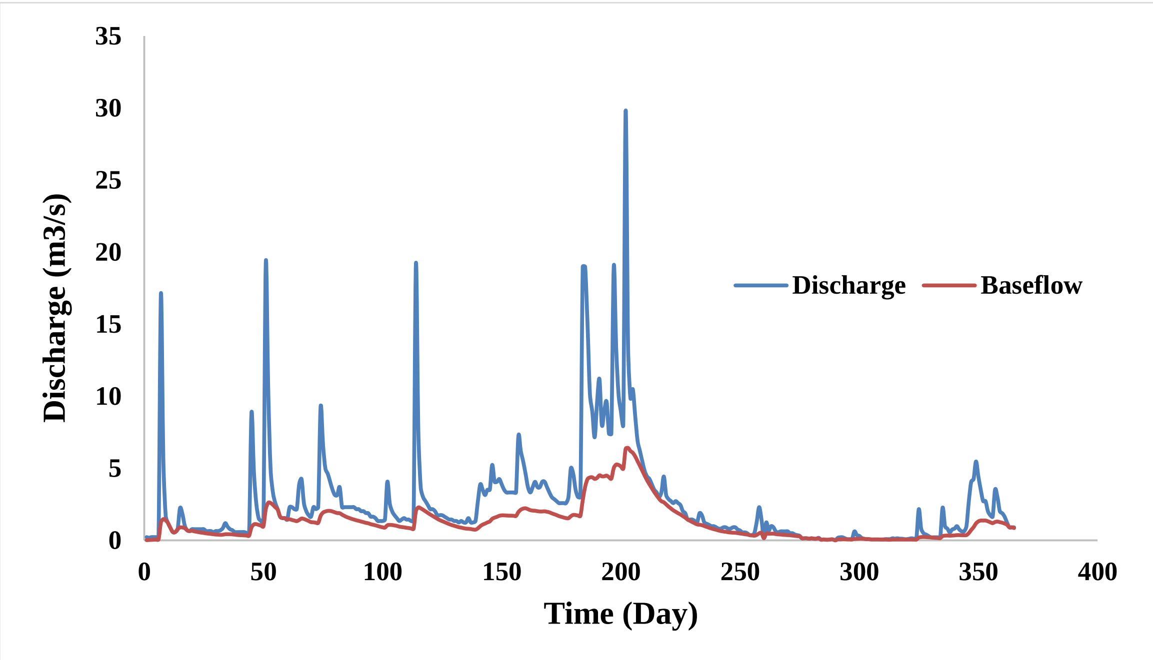

Fig. 2. Hydrograph separation in a part of the study period of Shirgah (Kasilian) station

3.3.2. Extraction of the flow duration curve indices

One of the important parameters in hydrological studies is FDC and related indices. This curve is obtained from the cumulative plotting of river discharge concerning to time and is frequently used to compare regimes of different basins. The shape of the curve is also a reflection of the influence of climatic and physiographic components on river flow and the hydrological response of the basin. (Alizadeh. 2007). This curve is normally extracted from the entire record of a study period, but this method does not provide information about the fluctuations of the curve from year to year and shows high uncertainty in the estimates.

Some researchers have suggested that FDC be calculated separately for each year and then the average of each indicator calculated separately.

This method represents a curve that is less affected by the fluctuations of the recording period (Vogel and Fennessey, 1994). In this research, this method has been used to plot FDC and extract the related percentiles. Figure 3 shows an example of FDC in one of the studied catchments.

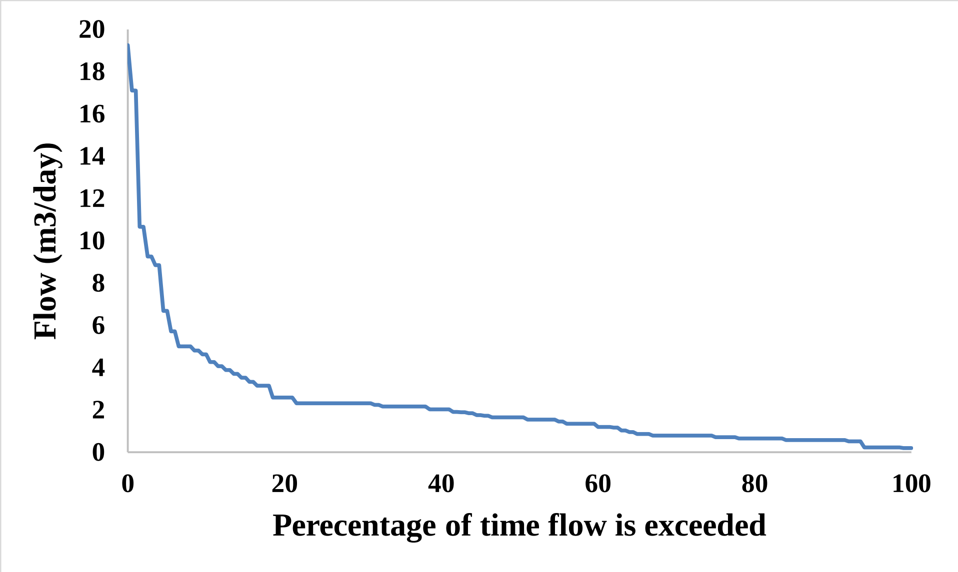

Fig. 3. Flow duration curve of the Shirgah (Kasilian) station

3. Results and discussion

As can be seen from Table 1, most of the river flows in the study area are related to the base flow and the annual average of the base flow index in the whole study period fluctuates between a minimum of 0.50 and a maximum of 0.69. The high ratio of the share of subsurface flows in the region shows the importance of research on the low flow indicators. The correlation relationships between the base flow and FDCI were presented in Figure 4. As can be seen, the appropriate correlation with a coefficient of determination above 68% indicates the ability to use these indicators to predict bae flow in the research area. .Flows proportional to the Q_{25} in the study area show the highest compliance and correlation with the coefficient of determination of 97% with the base flow. This adaptation can be used to determine the amount of base flow using FDCI.

However, due to the uncertainty of the actual amount of base flow and the fact that the base flow in this research was extracted only by one method, can only be generalized to the values obtained from this method and for regional generalization, the other methods should also be tested.

The correlation relationships of FDCI with MAM for 3, 7, 15, 30 days and the corresponding regression relationships are presented in Table 2. As can be seen, there was a strong relationship between MAM three-day and all four FDCI (Q_{25}, Q_{75}, Q_{90}, Q_{95}). The values of the coefficient of determination of 74, 90, 91 and 92 percent, respectively, belong to Q_{25}, Q_{75}, Q_{90}, and Q_{95}. This high rate of coefficient of determination as well as the low standard error indicates the appropriate ability of these indicators to predict the flow for at least three days. Meanwhile, the Q_{95} index shows more value due to the higher coefficient of determination and less standard error. In addition, the high level of correlation can indicate the ability to use these indicators as an alternative to hydrological analysis of the region.

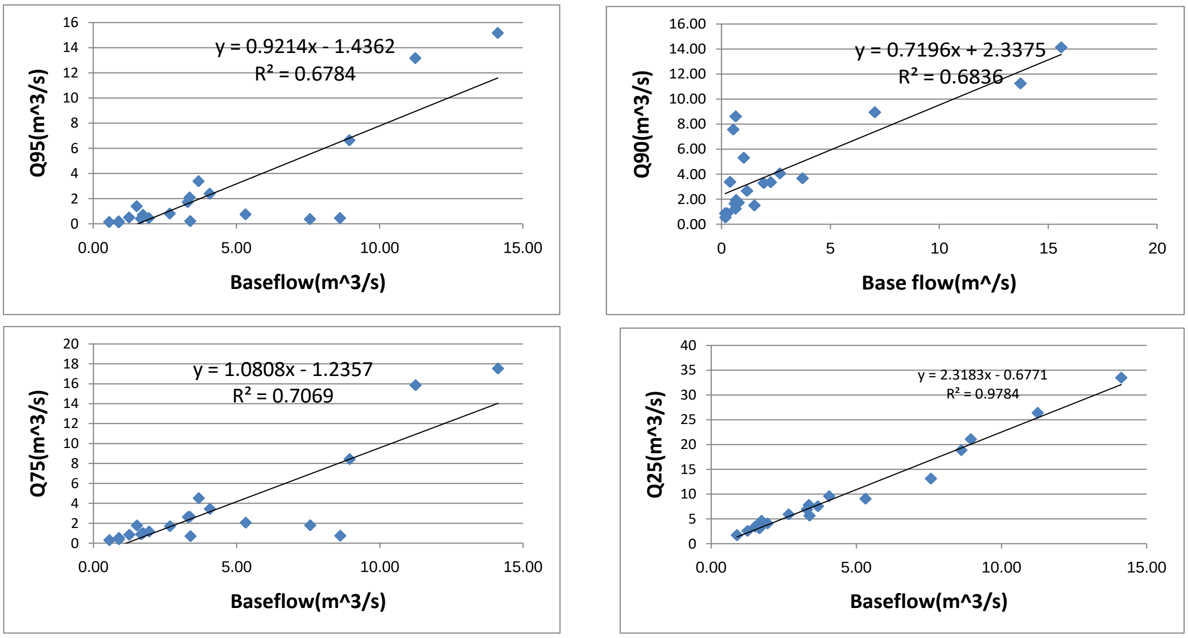

Fig. 4. Correlation relationship of base flow with flow duration curve indices

The MAM 7-day also showed similar correlation relationships with the MAM 3-day. Thus, the coefficient of determination of all four FDCI (Q_{25}, Q_{75}, Q_{90}, Q_{95}) were 72, 90, 91 and 92 percent, respectively. Percentages of time exceedance at the end of FDC have a higher correlation with MAM7 days. So in the case of Q_{95} with a standard error of 0.1 and a coefficient of determination of 0.92. It has more value as a predictor.

Table 2. Regression models of low flow indices in the research area

Low flow index	Regression model	R^2	SE	p-value
MAM3	$3.4337Q_{25}+5.4832$	0.7484**	0.07	0.000
MAM3	$2.0822Q_{75}+1.0736$	0.9079**	0.07	0.000
MAM3	$1.8699Q_{90}+0.6426$	0.9166**	0.06	0.000
MAM3	$1.8247Q_{95}+0.4757$	0.9207**	0.06	0.000
MAM7	$2.9016Q_{25}+5.5076$	0.7243**	0.09	0.000
MAM7	$1.7858Q_{75}+1.0532$	0.9051**	0.07	0.000
MAM7	$1.606Q_{90}+0.6212$	0.9165**	0.07	0.000
MAM7	$1.5672Q_{95}+0.4548$	0.9205**	0.01	0.000
MAM15	$-0.5577Q_{25}+15.26$	0.1374**	0. 50	0.000
MAM15	$-0.212Q_{75}+5.6771$	0.0655**	0.43	0.000
MAM15	$-0.1806Q_{90}+4.67$	0.0595**	0.51	0.000
MAM15	$0.1732Q_{95}+4.3777-$	0.0577**	0.45	0.000
MAM30	$1.6927Q_{75}+0.832$	0.9173**	0.01	0.000
MAM30	$1.5217Q_{90}+0.4231$	0.9281**	0.03	0.000
MAM30	$1.4845Q_{95}+0.2622$	0.9316**	0.03	0.000
MAM30	$2.7395Q_{25}+5.1652$	0.7282**	0.03	0.000

**. Correlation is significant at the 0.01 level (2-tailed)., R^2= Coefficient of determination, SE=Standard Error

As the continuity of the minimum flows increases, it is expected that the correlation trend will continue as in the previous, but despite the expectation, the MAM 15 days' lacks correlation with FDCI and has shown a large standard error. Therefore, it cannot be used for hydrological analysis of the research area and is not recommended.

In mean annual 30, days average minimum flow (MAM30); we see an increase in the correlation relationship so that the coefficient of determining of MAM30with four FDCI were 93,92,91,72, and in this case, whatever percentages The closer it gets to dehydration indicators, the higher the correlation with the flow for at least 30 days. In this case, low flow part of the FDC has a higher correlation with MAM30. In comparison, MAM30 has shown the highest coefficient of determination with FDCI, and is recommended for low flow analysis and drought analysis of the research area. In addition, the validity of using Q_{75}, Q_{90}, and Q_{95} indices were in the same range, and all indices above Q_{75} can be used to analyze low flow.

4. Conclusion

In this study, "9" low flow indices, including BFI and MAM,3,7,15,30 -day and four FDCI (Q_{25}, Q_{75}, Q_{90}, Q_{95}) from the daily stream flow data some of hydrometric stations of Caspian basin of Iran were surveyed over for period of 30 years. Appropriate correlations between base flow and FDCI showed the ability to predict base flow using FDCI. However, with caution, this can be applied to base flow separated by one parameter recursive digital filter method, and requires more testing to match it with the values obtained from other methods. MAM of 3, 7 and 30 days have a high correlation with FDCI and can be recommended for hydrological analysis of the research area.

The MAM 15 days' lacks correlation with FDCI and lacks the necessary validity to analyze the low flow conditions of the research area.

5. Acknowledgments

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6. Conflicts of Interest

No potential conflict of interest was reported by the authors

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