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Evaluation of Base Flow Index in Lake Urmia Basin Using One Parameter Digital Filter Method

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A B S T R A C T

Lake Urmia is a terminal hyper-saline lake, designated as a UNESCO Biosphere and wetland of international importance. Recent sharp decline in the lake water level is mainly addressed to the changes in the runoff patterns by means of climate changes and construction of more than 70 dams within the basin. In this study the main statistical characteristics of the runoff records in the most downstream hydrometric stations along the rivers that ends up to the lake is analyzed. Then, one parameter digital filter method is used to separate the base-flow from direct flow in runoff time series. It is concluded that the main source of runoff in the basin is base-flow provided by the groundwater which also is the main resource of water for rural, industrial and domestic use in the basin. It is obvious that the over consumption of the groundwater resources within the basin will put huge stress on the surface water as well as lake water level in the basin.

Keywords

Base-Flow
Lake Urmia
One-Parameter Digital Filter
Statistical Analysis
Stream Flow
Water Budget

1. Introduction

As a wetland located in North West of Iran, Lake Urmia was the largest permanent hypersaline lake in Middle East and the second in the World after the Great Salt Lake (Karbassi et al., 2010 and Hassanzadeh et al., 2012). It is located between 44°07'-47°53' Northing longitudes and 35°40'-38°30' Easting latitudes. Lake Urmia is 140 km long from North to South and 85 km wide from East to West in high water periods. Lake Urmia has a closed basin extending over West Azerbaijan, East Azerbaijan, and Kurdistan provinces of Iran. The borders of Turkey in West, and Iraq in South West surrounds the lake basin while the Northern, Eastern, and Southern parts of the basin are located within the Iranian territories. It is on the migration route of many birds and a home to unique species named *Artemia Urmiana* (Pengra., 2012). In late 1990s a sharp decline associated with the lake water level was addressed to the construction of more than 70 dams in the basin. Since then, debate between researchers and decision makers about the causes and cones of the lake's surface degradation became a major headline in the news and a socio-political concern for the country and the region. As surface runoff is the combination of groundwater water contribution with rainfall or snowmelt, it is important to discuss the properties of runoff in details. Hence, many studies have focused on different aspects of runoff in Lake Urmia basin. As example to mention, (Abbaspour et al., 2012; Hassanzadeh et al., 2012 and Kakahaji et al., 2013) used runoff as one of the main input variables in modeling Lake Urmia water level. Farajzadeh et al., 2014 used artificial neural network to model rainfall-runoff relationship in Lake Urmia basin.

(Burgan et al., 2017) compared the Shahar-Chay River from Lake Urmia basin with the Akarcay from Turkey considering the intermittency of both rivers. Recently, (Vaheddoost and Aksoy., 2018) investigated the quota of groundwater and base flow on the streamflows ending to the lake using analytical, (UKIH., 1980) and recursive digital filter (RDF) methods. It was concluded that more than 70 percent of the runoff ending to the lake is born in the shape of base flow in the streams. In this respect, this study is another attempt to evaluate the base flow index at the most downstream stations of the rivers ending

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to the Lake Urmia using another type of filtering method called, one parameter digital filter method (Nathan et al., 1990).

2. Materials and Methods

Data used in this study are provided by Iranian Water Resource Management Company (IWRMCo.) as daily time series. There are 18 major rivers in the basin that end up in Lake Urmia; namely Zola, Khorkhoreh, Nazloo, Ruzeh, Shahar, Baranduz, Cheshmeh-Dul, Gadar, Mahabad, Simineh, Zarrineh, Leylan, Maragheh, Sufi, Ghala, Azarshahr, Aji and Dariyan ordered counter clockwise starting at the north of the lake. Almost all of these rivers can be classified as intermittent or ephemeral which frequently go dry during the year. Thus, runoff characteristics of the rivers should play important roles on any decision or study linked to Lake Urmia.

In this respect, the most downstream gauging stations of the rivers before they enter into the lake water body were selected for the analysis of this study. Figure 1, shows the rivers considered and allocated stations selected for this aim. Characteristics of runoff time series such as consistency and randomness in the gauging stations at monthly and annual time scales in the time series were examined by the double mass curve, run test, and the Spearman Rank Order Correlation test. Results of the tests are provided in Table 1 and Figure 2 together with the amount of contribution of each river. It should be noticed that the Leylan River was excluded from the analysis as only a one-year record is available.

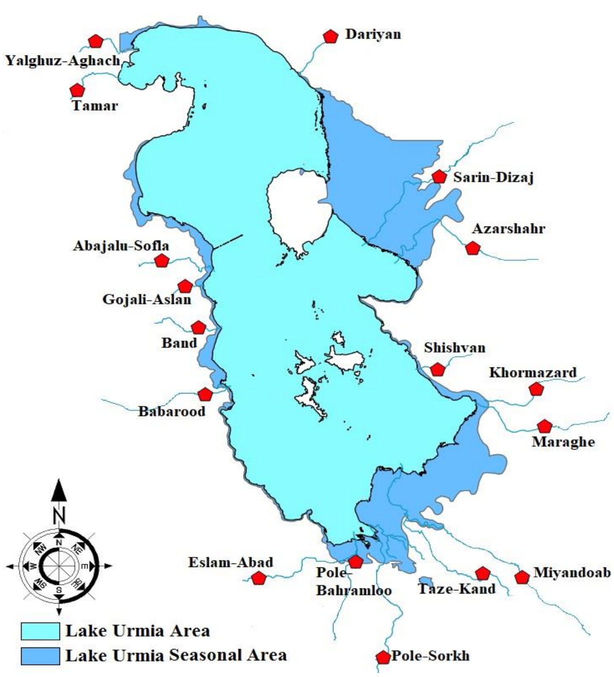

Figure 1.River network around Lake Urmia

As seen in Table 1, runoff time series at different time spans in most downstream stations are consistent both at monthly and annual scales. None of the time series at monthly scale are random which implies high amount of self-dependence and/or delay in time maybe due to the snowmelt or groundwater contribution. Figure 2 shows that Zarrineh river in one hand brings almost half of the whole surface runoff into the lake while the total contribution of Dariyan, Sufi, Khorkhore and Cheshme-Dul is less than 1%. This shows the difference between the share of contribution of the rivers flowing into Lake Urmia. As a further investigation, Figure 3 shows the monthly average contribution of the rivers into the lake. It is seen that the 8th month of the water year, May, has the highest contribution to the runoff ending in the lake. In the summer month, August, the lowest runoff contribution is observed. Contribution of Zarrineh river is noticeable throughout the year. Thus, a detailed analysis on this particular river could provide more information about the runoff contribution in the lake water budget.

Table 1. Characteristics of monthly and annual runoff time series at the most downstream gauging station

River	Station	Monthly		Annual	
		Consistent	Random	Consistent	Random
Zola	Yalghuz-Aghach	Yes	No	Yes	No
Khorkhoreh	Tamar	Yes	No	Yes	No
Nazloo	Abajalu-Sofla	Yes	No	Yes	No
Ruzeh	Gojali-Aslan	Yes	No	Yes	No
Shahar	Band	Yes	No	Yes	Yes
Baranduz	Babarood	Yes	No	Yes	Yes
Cheshme-Dul	Eslam-Abad	Yes	No	Yes	No
Gadar	Pole-Bahramloo	Yes	No	Yes	Yes
Mahabad	Pole-Sorkh	Yes	No	Yes	Yes
Simineh	Taze-Kand	Yes	No	Yes	No
Zarrineh	Miyandoab	Yes	No	Yes	Yes
Maragheh	Maragheh	Yes	No	Yes	Yes
Sufi	Khormazard	Yes	No	Yes	Yes
Ghala	Shishvan	Yes	No	Yes	Yes
Azarshahr	Azarshahr	Yes	No	Yes	Yes
Aji	Sarin-Dizaj	Yes	No	Yes	Yes
Dariyan	Dariyan	Yes	No	Yes	No

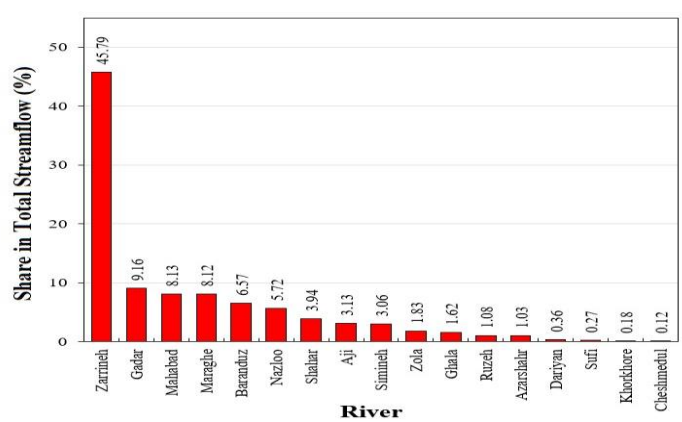

Figure 2. Contribution of each river in Lake Urmia runoff

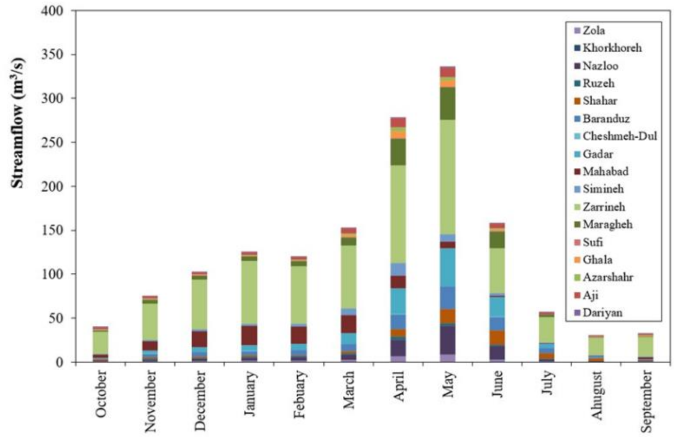

Figure 3.Average monthly contribution of rivers into the lake water budget

Base-flow separation methods exist in order to understand how effective base-flow is on the total contribution of lake basin in the form of surface runoff. Base-flow usually is provided by means of permanent contribution of groundwater while direct flow is usually provided by precipitation or snowmelt in the basin. The ratio of base-flow volume to the total runoff volume is defined as base-flow index (BFI) calculated at each streamflow gauging station. There are two types of base flow separation methods namely, event-based and continuous. In this respect, some time series better suited to continuous hydrographs over a long term period in which a digital filter is usually used to separate the base flow from the direct flow. One of these filters, used in continuous base flow separation is called single parameter digital filter application or one-parameter digital filter method (OPDFM) (Nathan et al., 1990 and Echhrdt., 2005).

In this method, α as the base flow filter parameter is obtained with algorithm at each time step as

$$R_{k+1} = \alpha R_k + \frac{(1+\alpha)}{2}(Q_{k+1} - Q_k) \quad (1)$$

considering R_k, and Q_k as direct runoff and streamflow at time step k respectively. Flowingly, at each time step check if $R_{k+1} < 0$, then $R_{k+1} = 0$; and if $R_{k+1} > Q_{k+1}$ then $R_{k+1} = Q_{k+1}$ and finally compute base flow, B, as $B_{k+1} = Q_{k+1} - R_{k+1}$.

3. Results and discussion

As the most important river contributing the lake, the Zarrineh river daily streamflow time series is analyzed in details together with the results of BFI calculated in other rivers. Figure 4 shows the daily streamflow time series of Zarrineh river from October 1987 to September 1994 (2562 daily flow data items). The observed daily streamflow time series is given together with base-flow time series calculated by OPDFM. It is obviously seen that base-flow is the dominant component of the runoff in the Zarrineh River Time series.

A deeper look at the average BFI in Figure 5, arranged for the time period used in the analysis shows that, the OPDFM calculates a BFI much higher than 50%. In this respect, in the Spring, BFI approaches its lowest value indicating that the wet season runoff experiences higher contribution of direct flow compared to the dry seasons. In June, the highest BFI of 90% is calculated. This is the beginning of the summer season when agricultural lands need more water before the harvesting season. As groundwater is the main source of water in the basin, over-consumption of groundwater will lead to dramatic decline in the base-flow which shares more than 70% of runoff in the Zarrineh river. In addition, with comparison of Figures 3 and 5, a sudden cutoff in precipitation or snowmelt is observed in the transition between May and June which puts extra stress on groundwater resources.

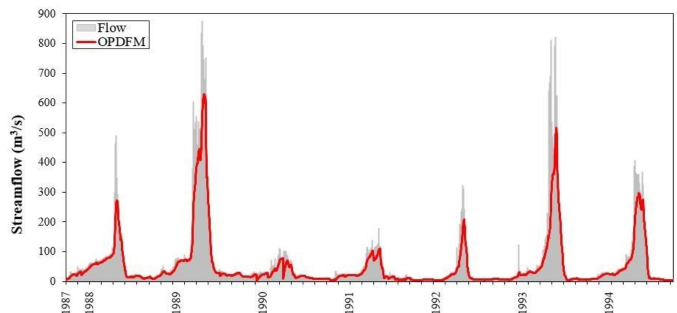

Figure 4. Baseflow separation in Zarrineh river using Local Minimum, Recursive Digital Filter and One-Parameter Digital Filter

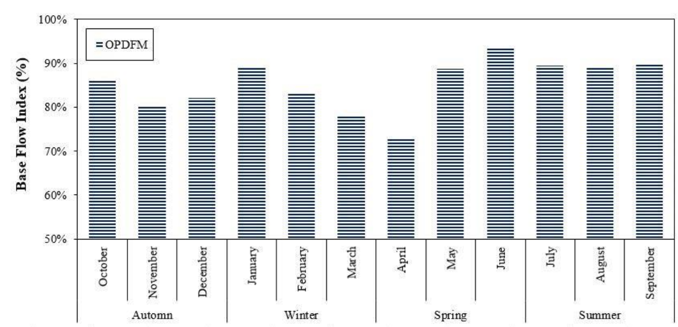

Figure 5. BFI calculated in Zarrineh river at monthly time scale

Table 2 shows BFI calculated for all rivers discharging into Lake Urmia. In general, BFI in the Lake Urmia basin is not lower than the 2/3 of the total runoff. Particular examples can be mentioned such as Aji river with the lowest base-flow contribution of 36%; Shahar-Chay and Cheshmeh-Dul with base-flow contribution exceeding 70%. Rather than these extreme example with minor total contribution it is important to notice that Zarrineh river as the main stream that brings runoff into Lake Urmia water body has a base-flow contribution about 77% of the total flow.

Table 2. BFI calculated for all rivers in the basin

River	Station	Q (m^3/s)	OPDFM	
			BFI (%)	Q_b (m^3/s)
Zola	Yalghuz-Aghach	0.99	60.30	0.60
Khorkhoreh	Tamar	0.04	71.24	0.03
Nazloo	Abajalu-Sofla	5.84	71.40	4.17
Roozeh	Gojali-Aslan	0.86	73.72	0.63
Shahar-Chay	Band	4.96	78.29	3.88
Baranduz	Babarood	6.53	67.21	4.39
Cheshmeh-Dul	Eslam-Abad	0.11	86.04	0.09
Gadar	Pole-Bahramloo	7.51	68.47	5.14
Mahabad	Pole-Sorkh	8.69	70.13	6.09
Simineh	Taze-Kand	2.48	61.34	1.52
Zarrineh	Miyandoab	40.24	76.52	30.79
Maragheh	Maragheh	2.32	75.19	1.74
Soofi	Khormazard	4.81	61.41	2.95
Ghala	Shishvan	1.25	60.00	0.75
Azarshahr	Azarshahr	1.49	64.77	0.97
Aji	Sarin-Dizaj	6.56	36.08	2.37
Dariyan	Dariyan	0.49	66.16	0.32
	Total Flow (m^3/s)	95.17		66.45
	Average BFI (%)		67.55	

4. Conclusions

Lake Urmia, is one of the most important wet lands and protected hyper-saline lakes in the world that deals with a gradual decline in its water level. Construction of more than 70 dams on the rivers in the basin was addressed as one of the main reasons of the lake atrophy. Most of the literature on runoff characteristics in the basin has focused on simple analysis and modelling efforts. Thus, a statistical analysis of streamflow data with a focus on base flow is found to be important. Results of the analysis indicate that groundwater has a huge contribution in runoff in the basin. The most vulnerable season is the beginning of the summer when, in one hand, rivers get dry due their intermittent or ephemeral character and water demand is at its peak for the irrigated agricultural lands on the other hand, which is provided from groundwater storage historically. It is therefore important to imply that protection of groundwater resources in Lake Urmia basin is vital for protection planning of the lake against shrinkage in its water level.

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