Impact of climate change and human factors on water resources variations in reservoir dams (case study: Lighvan River, Iran)

Impact du changement climatique et des facteurs humains sur les variations des ressources en eau dans les barrages réservoirs (étude de cas : rivière Lighvan, Iran)

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Abstract. In recent years, runoff of basins has changed due to climate change and human activities. Since river flow changes play a key role in reservoirs water resources planning purposes, the analysis of the role of climatic and human factors in river flow changes is of great importance in reservoirs development plans. In this study, the effect of climate change and human activities on the runoff responses was examined using hydrologic sensitivity analysis in the Lighvan basin located in the northwest of Iran. The Vanyar dam is located in downstream of the Lighvan basin. The Mann–Kendall test and the Pettitt test were applied to identify the monotonic and rapid trends respectively, in hydro-climatic data series. The results showed that there was negative trend in discharge data series. The effect percentages of the human factors and climatic factors on runoff reduction were 65%-84% and 16%-35%, respectively. Therefore, in addition to the role of climate change, there is a need to pay more attention to the impacts of human activities in the upstream of dams. Also, according to the rate of changes of climatic and human factors, the design and planning of water resources of reservoirs should be improved and adapted. Keywords: Climate change; Human activities; Lighvan River; Pettitt; Reservoir.

Résumé. Ces dernières années, le ruissellement des bassins a changé en raison du changement climatique et des activités humaines. Dans la mesure où les changements de débit des rivières jouent un rôle clé dans la planification des ressources en eau des réservoirs, l'analyse du rôle des facteurs climatiques et humains dans les changements de débit des rivières est d'une grande importance dans les plans de développement des réservoirs.

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Dans cette étude, l'effet du changement climatique et des activités humaines sur les réponses au ruissellement a été examiné à l'aide d'une analyse de sensibilité hydrologique dans le bassin de Lighvan situé au nord-ouest de l'Iran. Le barrage de Vanyar est situé en aval du bassin de Lighvan. Le test de Mann-Kendall et le test de Pettitt ont été respectivement appliqués pour identifier les tendances monotones et rapides, dans des séries de données hydroclimatiques. Les résultats ont montré qu'il y avait une tendance négative dans les séries de données sur les sorties. Les pourcentages d'effet des facteurs humains et climatiques sur la réduction du ruissellement étaient respectivement de 65 % - 84 % et 16 % - 35 %. Par conséquent, en plus du rôle du changement climatique, il est nécessaire d'accorder plus d'attention aux impacts des activités humaines en amont des barrages. En outre, en fonction du rythme des changements des facteurs climatiques et humains, la conception et la planification des ressources en eau des réservoirs devraient être améliorées et adaptées.

1 Introduction

Hydrological changes have mainly been caused by natural (climatic) and human factors. In recent years, major changes have been made by human activities and climatic conditions in basins all over the world and as a result the river flows have decreased and occurrence of flood events has increased in some cases [1]. The issue of surface runoff reduction is one of the major challenges in water resources management, especially in reservoir dams in arid and semi-arid regions of Iran.

Understanding the factors of water resources changes, especially in dams and natural reservoirs, and determining the contribution of each of the effective factors in reducing surface runoffs and water resources are very important in solving the issues related to water resources management.

Different studies have been conducted by researchers about river flow variations. Jiang et al. (2011) used three methods to analysis the effects of climate change and human activities in the Laohahe basin in northern China. In order to determine the trend of the runoff changes, the non-parametric Kendall test, the Pettitt test and the cumulative accumulation curve of annual rainfall- runoff were applied. The results showed that, human activities were the main cause of runoff reduction in the period of 1980-2008 (89-93 percent), and the contribution of precipitation and potential evapotranspiration changes was only 7-11 percent. Guo et al. (2014) studied the effects of climate change and human activities on the runoff of two sub-basins of the Weihe basin using the Mann-Kendall test to analysis the hydroclimatic data series. In order to determine the point changes of the annual flow, the Pettitt test and cumulative rainfall-runoff curve were applied. The results showed that there is a negative trend and a change point of flow occurred in 1993 for both of the sub-basins. Based on hydrologic sensitivity analysis and hydrologic simulation model, the runoff reduction trend of both sub-basins was mainly due to human activities by effect percent of 59% to 77%. Similar researches have been made by Ma et al. (2010), Wang et al. (2011), Zhang et al. (2011), Gao et al. (2013) and Li et al. (2014).

The purpose of this research is analyzing the hydroclimatic factors changes and determining the role of natural and human factors on variations of the Lighvan River flow, which is one of the most important rivers of the upstream of Vanyar Dam, Iran. In recent years, due to the decrease in inflow, the planning of water resources of this dam and its purposes have changed several times.

2 Material and methods

2.1 Study area and hydro-climatic data

The study area is the Lighvan River basin, which is one of the sub-basins of the Ajichai River located in the north-west of Iran, which Vanyar Dam constructed on this river. There are two hydrometric stations in the Lighvan basin, where the Lighvan is located on the upstream and Hervy in downstream of basin. Some information about these stations is listed in Table 1. Time series data of the river flow were collected at the Hervy station for the period of 1970-2014. The climatic data of the basin were also collected from the meteorological stations in the upstream and downstream of the basin for the period of 1971-2014. The location of the Lighvan basin is shown in Figure 1.

Table 1. Information of the studied hydrometric stations.

Station	Location	Elevation (m)	Establish Year	Data (year)	Equipment	Cathment Area (km^2)	Length of Main Stream (km)	Annual Discharge (cms)
Lighvan	46°-26', 37°-50'	2150	1953	54	Gauge, Limnograph, Data logger	76	17	0.789
Hervy	46°-29', 37°-55'	1920	1970	44	Gauge, Limnograph,	186	28.5	0.604

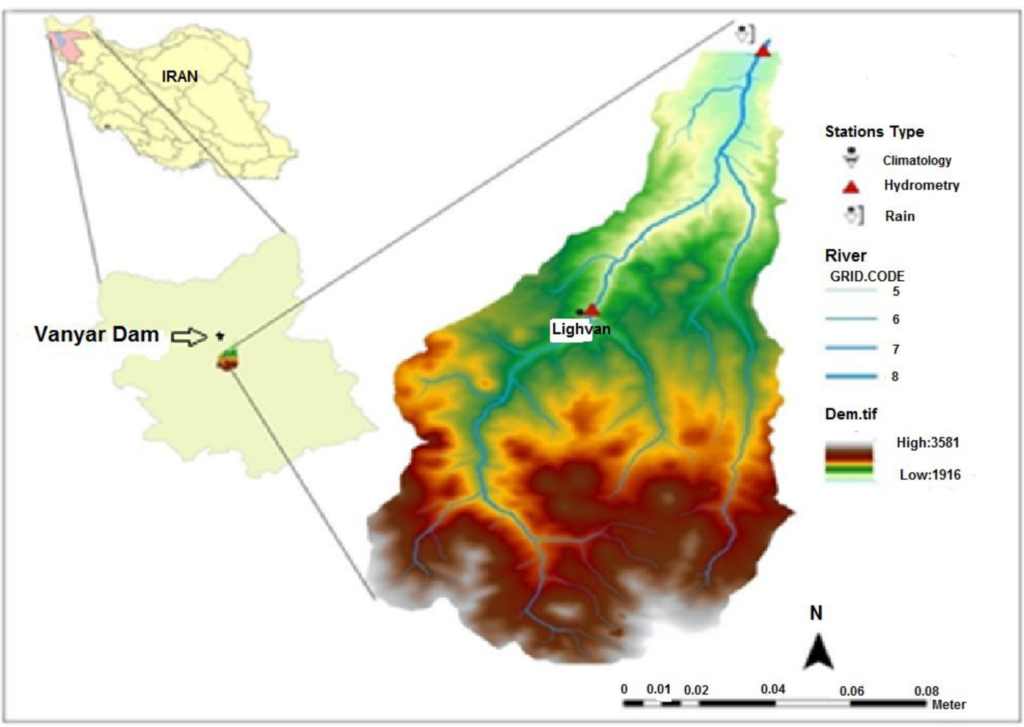

Fig. 1. Location of the Lighvan basin and the Vanyar Dam.

2.2 Trend analysis of monotonic and rapid changes

2.2.1 Mann-Kendall modified test

The conventional nonparametric Mann-Kendall test (MK1), first presented by Mann (1945), and then developed by Kendall (1975). The modified version has been presented by Hamed and Rao (1998). In this method, the effect of all autocorrelation coefficients is eliminated from the data series and used for series, whose autocorrelation coefficients are at least in one significance.

2.2.2 Pettitt Test

The Pettitt test is a nonparametric test that was presented by Pettitt (1979) to detect a change point in the continuous hydrological or climatic data series.

2.3 Determining the contribution of climatic and human factors to runoff changes

In order to quantify the effects of climate change and human activities on the streamflow, an empirical model presented by Parks and Madison (1985) and Li et al. (2007) was developed. The general form of the applied model is as follows [15]:

$$Q_k = a\,(P_k/PE_k)^{b} + c \tag{1}$$

In this research, the above equation (8) was developed using other climatic parameters used in the trend analysis section. For example, the proposed equation in this study can be as follows:

$$Q = f\,(P_{annual},\ P_{snow}/P,\ FD,\ T_{min},\ T_{mean},\ T_{max},\ RH\ \ldots) \tag{2}$$

Where P_{snow}/P: ratio of snow to total precipitation, FD: number of frost days and RH is relative humidity. The best relationship was obtained while applying multiple regression (MLR) and Ridge regression methods. For the formation of hydrological models, firstly the correlation of single variables with streamflow values was investigated and effective variables were determined (for example Q and P, Q and Tmean, Q and RH, etc).

The contribution of climatic and human factors to total runoff variations in terms of percentages can be derived from Eq. (5) and (6), respectively [15]:

$$\Delta Q = \Delta Q_c + \Delta Q_h \tag{3}$$

Where ΔQ is total runoff variations, ΔQ_c and ΔQ_h are changes of runoff related to climatic and human factors, respectively.

$$\Delta Q_c = Q_{sim} - Q_{nat} \text{ and } \Delta Q_h = Q_{sim} - Q_{imp} \tag{4}$$

$$C_c = \Delta Q_c/\Delta Q * 100 = (Q_{sim} - Q_{nat})/\ \Delta Q * 100 \tag{5}$$

$$C_h = \Delta Q_h/\Delta Q * 100 = (Q_{sim} - Q_{imp})/\ \Delta Q * 100 \tag{6}$$

Where the indices c, h, sim, nat, and imp are related to the climate, human activities, simulated, natural and influenced periods.

3 Results and Discussion

3.1 Trend analysis of hydro-climatic factors

Trend analysis of the discharge data of the hydrometric stations showed that the annual flow at the Hervy Station located in the downstream of the basin has a downward trend. There are also negative trends for all months of the year. The most negative trend was for the July. Also, in the Lighvan Station located at the upstream of the basin, annual discharge was declined but its significance level is less than 10% (Z = -1.03). The river flow was declined during the months of year except the April and May, and the downward trend is significant from the June to September. Most of climatic variables of the basin such as precipitation, temperature (mean, maximum, minimum and difference of maximum- minimum) and relative humidity were examined. The results showed that most of the temperature variables of the basin were increasing at different time scales. In the case of precipitation, the results showed that there is a decrease in the trend of all characteristics of the precipitation in the spring, which indicates its negative effects on the runoff. The results of the trend test for the seasonal and annual scales are presented in Table (2). The values in the table are the Z values of Mann- Kendall test.

In study of the existence of change point in the studied time series using the Pettitt test, it can be found that for the Hervy station, a change point is detected in 1995, and data of annual discharge was divided into two periods of 1970-1995 and 1996-2014. But in the upstream of the basin at the Lighvan Station, the change point was not detected, which is probably due to the effect of human activities on the downstream. Figure 2 shows the point changes of discharge in upstream and downstream of the Lighvan basin. Comparison of the average discharge in the Hervy Station in the two periods indicates 36% decrease in the recent period (affected) compared to the natural period (first period).

Table 2. Results of the Mann-Kendall test (*Z* values) for the hydro-climatic variables of Lighvan basin.

Variable Scale	Q-Hervy	Q-Lighvan	P	T_{mean}	T_{max}	T_{min}	T_{max}-T_{min}	RH
Fall	**-2.38**$^{++}$	**-1.77**	**1.70**	0.22	1.16	0.01	0.74	0.08
Winter	**-3.12**$^{++}$	-0.68	**1.80**	**2.33**$^{++}$	**1.86**	**1.82**	1.61	-1.63
Spring	**-1.87**	-0.29	-0.76	**2.33**$^{++}$	**1.86**	0.71	1.61	-0.60
Summer	**-3.30**$^{++}$	**-2.38**$^{++}$	**1.79**	0.50	1.39	-0.28	0.63	-0.16
Year	**-1.73**	-1.03	0.14	1.52	**1.82**	0.54	1.39	-0.61

Note: Bold numbers, and numbers with + and ++ signs are significant at 10%, 5% and 1%, respectively. Q, P, T and RH are streamflow, precipitation, temperature and relative humidity, respectively.

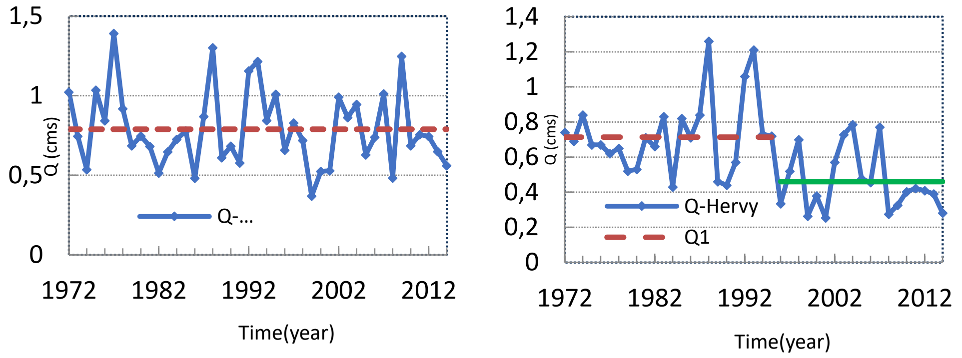

Fig. 2. Changes in annual discharge of the Lighvan River in upstream (Lighvan Station) and downstream of the basin (Hervy Station).

3.2 Determination of contribution of the climatic and human factors in runoff reduction

The Guo model (Eq. 1), which was obtained during the first period and used for runoff predicting in the second period (affected period) is as follows:

$$\mathbf{Q_{sim}} = -0.549 + 5.253E\text{-}04\ \mathbf{P} - 2.744E\text{-}02\mathbf{T_{mean}} + 1.091E\text{-}02\ \mathbf{RH} + 2.982E\text{-}03\mathbf{FD} + 1.765\ \ \mathbf{Snow/p}_{\mathbf{Spring}} + 8.931E\text{-}04\mathbf{P_{Autumn}}$$

Where P: precipitation (mm), T_{mean}: mean temperature (°C), RH: relative humidity (%), FD: number of frost days all yearly, and Snow/p $_{Spring}$: ratio of snow to total precipitation in spring and P_{Autumn}: precipitation in autumn season (mm).

The contribution of each of the climatic and human factors in reducing the discharges of the Lighvan River was calculated based on the equations (4-6), for the Hervy Station (Table 3).

Table 3. The results of contribution of climatic and human factors in river flow reduction.

Model	$\bar{Q}_{nat}$ (cms)	$\bar{Q}_{imp}$ (cms)	ΔQ (cms)	C (%)	$\bar{Q}_{sim}$ (cms)	C_C (%)	C_h (%)
Model 1-1	0.724	0.459	0.265	36.6	0.663	**23**	**77**

Where $\bar{Q}_{nat}$ and $\bar{Q}_{imp}$ are average of discharge in natural and impacted periods (observed), respectively. ΔQ is total changes of streamflow and C is percentage of this changes (ratio of impacted discharge to natural discharge). Also, $\bar{Q}_{sim}$ is average of simulated discharge in impacted period.

As it is seen in Table 3, in the model 1-1 the contribution of climatic and human factors in reducing the runoff of the river is about 23% and 77%, respectively. For the other model (1-2), these values were 16% and 84%, respectively. Moreover, the human factors were more effective than the climatic factors on the river flow reduction. It should be noted that in other selected models not presented here (used in this research), the contribution of human factors (about two third) was more than the climatic (about one third).

3.3 Discussion

Regarding to the results obtained in the selected model for streamflow prediction, variables such as $Snow/P_{spring}$ ratio and P_{autumn} and even *RH* have been included in various models and have an effective role in the amount of runoff, meaning that it is necessary to pay attention to the type of precipitation (snow) and temporal distribution of precipitation (autumn and spring seasons).

In the downstream of the basin (Hervy Station), the rapid change of streamflow was very significant and the monotonic downward trend was also more severe. Therefore, it could be argued that considering that the climatic conditions of the basin are almost uniform, the role of human actions such as cultivation changes (area and patterns) and water supply for urban areas is more prominent in streamflow changes.

Estimating the contribution of climatic and human factors in streamflow changes in the studied basin by using two models and other tested models (not presented here) showed that, the contribution of climatic factors resulted in up to one third of the total variation, and two thirds of the rest was related to human actions. Of course, if this research is done in other watersheds of the region, the results may vary, but it is expected to follow a general pattern (it is suggest to be repeated this study in several other basins). Examples of human factors influencing the flow of the river in the basin can be mentioned. One of them is the drilling of more than 60 wells for drinking water in villages of studied region and the city of Tabriz in the basin area in 2000-2001, which is generally harvested almost 500 liters per second. This has led to a drop in groundwater level and the feeding of the river has fallen from below-surface water. Also, Khaleghi (2014) in study of land use changes in the Lighvan basin showed that the residential areas increased by 88.9% and gardens by 28.2% between 2000-2012. The area of good rangeland has decreased by 44%, and as a result, dry cultivation has increased by 38.6%.

4 Conclusion

In this study, the reasons for the runoff changes in the Lighvan River, Iran were identified, and effect of the influencing factors, climatic and human factors, on runoff reduction were determined. It was found by results of the Pettitt test that the time of change point for the most variables used in the study are mid-1990s. What can be deduced from the analysis of the effects of climatic and human factors on the river flow changes is that the role of human activities is more than the climatic factors on the runoff changes. In other words, the effect percentages of the human factors and climatic factors in all the models were 65%-84% and 16%-35%, respectively. Therefore, the impact of human activities in the river flow reduction was significant. This states the importance of avoiding harmful human activities and adopting appropriate strategies, such as controlling water consumption and optimizing patterns of cultivation to protect water and soil resources in the catchment. This study can be a reference for the development and management of the water resources of reservoir dams and environment protection.

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