Analysis of the role of climatic and human factors in runoff variations (case study: Lighvan River in Urmia Lake Basin, Iran)

R. Kanani, A. Fakheri Fard, M. A. Ghorbani and Y. Dinpashoh

ABSTRACT

In recent years, river flows have significantly decreased due to regional or global climate change and human activities, especially in the arid and semi-arid regions. In this study, the effects of climate change and human activities on the runoff responses were examined using hydrologic sensitivity analysis and hydrologic model simulation in the Lighvan basin located in the northwest of Iran. The Mann–Kendall test was applied to identify the trends in hydroclimatic data series. Also, the Pettitt test was used to detect change points in the annual discharge values and climatic variables. The results showed that there was negative trend in discharge data series, and examination of the climatic factors indicated that there was an increase in the temperature values and a decrease in the relative humidity values at the basin. The rapid changes in runoff values and most of the climatic variables occurred in the mid-1990s. The effect percentages of the human factors and climatic factors on runoff reduction in all the models used were 65–84% and 16–35%, respectively. Therefore, the impact of human activities on the river flow changes was significant.

Key words | change point, climate change, human activities, Lighvan River, Pettitt

R. Kanani (corresponding author)
A. Fakheri Fard
M. A. Ghorbani
Y. Dinpashoh
Water Resources Engineering,
Faculty of Agriculture,
University of Tabriz,
Tabriz,
Iran
E-mail: *rezakanani@gmail.com*

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, river flows have decreased and the occurrence of flood events has increased in some cases (Hood 2011). The issue of surface runoff reduction is one of the major challenges in water resources management, especially in arid and semi-arid regions of Iran. Urmia Lake, located in northwest Iran, is the second largest hypersaline lake worldwide and known as one of Artemia's main habitats in the world. During the past two decades, a significant water level decline has occurred in the lake (Okhravi *et al.* 2017).

Understanding the factors of water resources changes, especially natural reservoirs and lakes such as Urmia Lake, 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 analyze 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 1980–2008 (89–93%), and the contribution of precipitation and potential evapotranspiration changes was only 7–11%. Jones *et al.*

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(2006) studied the sensitivity of mean annual runoff in 22 Australian catchments to climate change using selected hydrological models. For this purpose, two lumped parameter rainfall–runoff models, SIMHYD and AWBM and an empirical model, Zhang01 were used. The results showed that the models display different sensitivities to both rainfall and potential evaporation changes. The SIMHYD, AWBM, and Zhang01 models show mean sensitivities of 2.4%, 2.5%, and 2.1% change in mean annual runoff for every 1% change in mean annual rainfall, respectively. Vaze *et al.* (2010) studied the performance of rainfall–runoff models for use in climate change studies. For this purpose, four rainfall–runoff models were investigated using long-term daily records of 61 watersheds in northeastern Australia. The results showed that the models, when calibrated using more than 20 years of data, can generally be used for climate impact studies where the future mean annual rainfall is not more than 15% drier or 20% wetter than the mean annual rainfall in the model calibration period. 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 analyze the hydroclimatic data series. In order to determine the change points 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 (59% to 77%). Tan & Gan (2015) estimated the direct influence of human activities and climate change effect to changes of the mean annual streamflow (MAS) of 96 Canadian watersheds based on the elasticity of streamflow in relation to precipitation, PET, and human impacts such as land use and cover change. Results showed that climate change generally caused an increase in MAS, while human impacts generally caused a decrease in MAS. Higher proportions of human contribution, compared to that of climate change contribution, resulted in the generally decreased streamflow of Canada observed in recent decades. The effects of climate change and human activities on the runoff of the Luan basin during the period 1956–2000 have been studied by Wang *et al.* (2016). The results indicated that in the annual variations, the role of climate changes and human activities was 40.9% and 59.1%, respectively. In human factors, water regulation in reservoirs plays a greater role than land use change (38.86% vs. 20.26%). Similar researches have been carried out by Ma *et al.* (2010), Wang & Hejazi (2011), Zhang *et al.* (2011), Gao *et al.* (2013), and Li *et al.* (2014). Reviewing these studies shows that various methods have been used by the researchers to determine the contribution of climatic and human factors in river variations, and the importance and role of climatic and human factors was different in different basins. The role of the climatic factors was greater than human factors in some basins, and in others, the human factors were more effective.

The purpose of this research is to analyze the hydroclimatic factor changes and determine the role of natural and human factors on variations of the Lighvan River flow, which is one of the most important rivers of the Urmia Lake basin, Iran. In the previous studies, the used climatic factors in climate elasticity models had included precipitation and evapotranspiration generally and details of the climatic factors were not considered. In this research, some effective variables such as the types and characteristics of precipitation and temperature-related variables (in monthly, seasonal, and annual time scales) were studied in detail. Therefore, the accuracy of previous models has increased.

MATERIAL AND METHODS

Study area and hydroclimatic data

The study area is the Lighvan River basin, which is one of the sub-basins of the Urmia Lake basin located in the northwest of Iran. Discharges of most of Iran's rivers, especially those in the Urmia Lake basin, have declined in recent years. The selection of Lighvan basin as a case study, other than its hydrological importance in supplying water resources in the region, has been due to the availability of suitable hydrometric and meteorological stations, and the length of the statistical period and data quality. There are two hydrometric stations in the Lighvan basin, Lighvan is located on the upstream and Hervy on the downstream of the basin. Some information about these stations is listed in Table 1. Time series data of the river flow were collected at Hervy station for the period 1970–2014. The climatic data

Table 1 | Information of the studied hydrometric stations

Station	Location	Elevation (m)	Established year	Data (year)	Equipment	Catchment area (km^2)	Length of main stream (km)	Annual discharge (cms or m$_3$/s)
Lighvan	46°–26′, 37°–50′	2,150	1953	54	Gauge, limnograph, data logger	76	17	0.789
Hervy	46°–29′, 37°–55′	1,920	1970	44	Gauge, limnograph	186	28.5	0.604

of the basin were also collected from the meteorological stations in the upstream and downstream of the basin for the period 1971–2014. The location of the Lighvan basin is shown in Figure 1. Table 2 presents the statistical parameters of the hydroclimatic data used.

Trend analysis of monotonic and rapid changes

Mann–Kendall modified test

The conventional nonparametric Mann–Kendall test (MK1) was first presented by Mann (1945) and then developed by Kendall (1975). The modified version was presented by Hamed & Rao (1998). In this method, the effect of all autocorrelation coefficients is eliminated from the data series and is suitable for autocorrelated data. First, the modified variance or V(S)* can be calculated as follows:

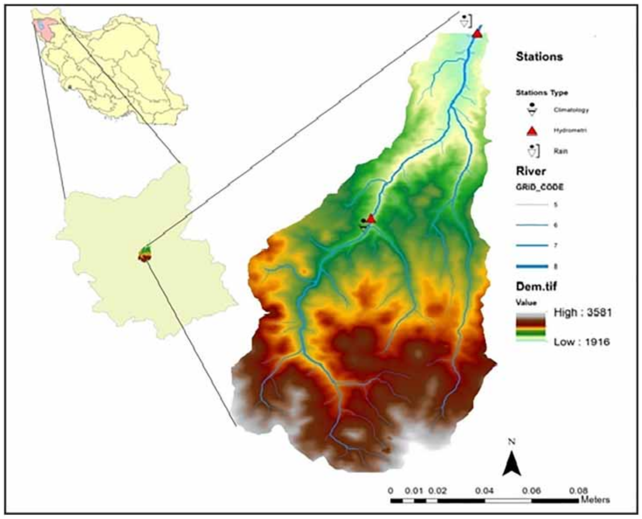

Figure 1 | Location of the Lighvan basin.

$$V(S)^* = V(S)\frac{n}{n^*} \tag{1}$$

where n/n^* is obtained from the following equation:

$$\frac{n}{n^*} = 1 + \sum_{i=1}^{n-1}(n-i)(n-i-1)(n-i-2)r_i \tag{2}$$

where r_i is the autocorrelation coefficient with lag i, and n is the number of data and $V(S)$ can be calculated from Equation (3):

$$V(S) = [n(n-1)(2n+5) - \sum_{i=1}^{n} t_i(t_i-1)(2t_i+5)]/18 \tag{3}$$

in which t_i groups with the same data are in the i^{th} category. To calculate the modified $\boldsymbol{Z}$ statistic (**MK3**), V(S) is replaced by V(S)*.

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. An appealing nonparametric test to detect a change and would be used as a

Table 2 | Statistical parameters of the hydroclimatic annual data

Variable	*Q*-Hervy (cm)	*Q*-Lighvan (cm)	*P* (mm)	T_{mean} (°C)	T_{max} (°C)	T_{min} (°C)	T_{max}–T_{min} (°C)	*RH* (%)
Mean	0.604	0.789	336.6	6.8	13.2	0.5	12.7	58.7
Max	1.258	1.391	516.1	9.2	16.6	3.1	16.8	69.4
Min	0.254	0.369	186.7	4.0	10.3	−1.9	10.0	46.8
Stdv	0.234	0.235	80.6	1.2	1.5	1.2	1.5	6.6

version of the Mann–Whitney two-sample test.

$$D_{ij} = Sgn(x_i - x_j) \tag{4}$$

where *Sgn* is a sign function. The $U_{t,T}$ statistic, which is equivalent to a Mann–Whitney statistic for testing, is calculated as follows:

$$U_{t,T} = \sum_{i=1}^{t} \sum_{j=i+1}^{T} D_{ij} \tag{5}$$

The $U_{t,T}$ statistic contains *t* values in the interval $1 \leq t < T$. For the test, the above statistics are used as follows:

$$K_T = max|U_{t,T}| \tag{6}$$

The change point is in K_T, and the probability of a K_T at 5% is approximated by the following equation:

$$p \cong 2\exp\left(\frac{-6K_T^2}{T^3 + T^2}\right) \tag{7}$$

Determining the contribution of climatic and human factors to runoff changes

Determining the contribution of natural and human factors in runoff changes is the main purpose of this research. In order to quantify the effects of climate change and human activities on the streamflow, an empirical model presented by Li *et al.* (2007) and Parks & Madison (1985) was developed. The general form of the applied model is as follows (Guo *et al.* 2015):

$$Q_k = \mathrm{a}(P_k/PE_k)^{\mathrm{b}} + \mathrm{c} \tag{8}$$

where *a*, *b*, and *c* are constant coefficients obtained from the normal (unaffected) period of time, *Q* is the runoff (cms), *P* is the precipitation (mm), *PE* is the potential evapotranspiration (mm), and *k* is the year's index. In this research, 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:

$$Q = f(P_{annual},\ P_{snow}/P,\ FD,\ (P > 10mm)/P,\ E_{pan},\ T_{\min},\ T_{mean},\ T_{\max},\ RH \ldots) \tag{9}$$

where P_{snow}/P is ratio of snow to total precipitation, *FD* is 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, first all the data used were validated and the outlier data were discarded. Then, the correlation of single variables with streamflow values was investigated and effective variables were determined (for example *Q* and *P*, *Q* and T_{mean}, *Q* and *RH*, etc.). The dependent variable was the time series of annual streamflow at the Hervy station during the first period. The climatic variables were defined in different combinations as inputs of the models. For MLR (forward method) SPSS and for ridge regression NCSS software were used.

The contribution of climatic and human factors to total runoff variations in terms of percentages can be derived from Equations (12) and (13), respectively (Guo *et al.* 2015):

$$\Delta Q = \Delta Q_c + \Delta Q_h \tag{10}$$

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

$$\Delta Q_c = Q_{sim} - Q_{nat} \text{ and } \Delta Q_h = Q_{sim} - Q_{imp} \tag{11}$$

$$C_c = \Delta Q_c/\Delta Q^* 100 = (Q_{sim} - Q_{nat})/\Delta Q^* 100 \tag{12}$$

$$C_h = \Delta Q_h/\Delta Q^* 100 = (Q_{sim} - Q_{imp})/\Delta Q^* 100 \tag{13}$$

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

Effective factors in runoff include climatic variables as well as the variables regarding human activities. The climatic variables studied in regression models that have an effect on runoff production include precipitation (amount, type, and classification of precipitation >5 mm, >10 mm, etc.) temperature (mean, max, min, max–min), relative humidity, number of frost days, and equivalent water of snowmelt in monthly, seasonal, and annual time scales. Data of pan evaporation in seven months of the year (April–October) were used (since in the other months there was a great deal of missing data). The impact of these variables was considered directly and indirectly on the basin runoff. The variables of temperature, evaporation, *RH*, and *FD*, by effect on *ET*, ultimately have an effect on runoff. Considering the importance of snow melting in the runoff of the basin, and that the flow of the river is snowy-rainy, snow is considered especially. Groundwater flow could be effective on the river's margin, but there is no piezometric network in the upstream of the basin, and is mainly located downstream of the basin. There are no reservoirs in the studied basin, and there are only a few small pools within the enclosed houses. Human factors are considered generally and were in the form of uses from the river and groundwater in the downstream of the basin due to the increase in rural population and land use change.

In another method applied in this research, for the second period of the Pettitt test, the new model is presented based on the new climatic data. That means, the input of the new model is the variables of *model 1-1* and the second period data are used. Thus, the coefficients of the variables in *model 1-2* will be different from the 1-1 model. First, the average simulated runoff in the second period is calculated based on the first model (*model 1-1*) and the second climatic model (*model 1-2*), and the difference between the two models is determined. Then, the ratio of this difference to the amount of simulated runoff derived from the first period model is considered to be the concept of human changes (ΔQ_h). The contribution of climatic (C_c) and human factors (C_h) in runoff changes can be calculated with the following relations:

$$\Delta Q_h = \frac{\bar{Q}_{SIM(1)} - \bar{Q}_{SIM(2)}}{\bar{Q}_{SIM(1)}} \tag{14}$$

in which $\bar{Q}_{SIM(1)}$ is the average simulated runoff based on the first period model and $\bar{Q}_{SIM(2)}$ is the average simulated runoff based on the second period model.

$$C_h = \frac{\Delta Q_h}{\frac{\Delta Q}{\bar{Q}_{nat}}} \times 100, \;\; C_C = 100 - C_h \tag{15}$$

In the above equation, ΔQ is the total runoff changes and $\bar{Q}_{nat}$ is the average natural discharge (observation) in the first period. A flowchart of the two methods used in this study is summarized in Figure 2.

RESULTS AND DISCUSSION

Trend analysis of hydroclimatic 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 (at a level of 10%). There are also negative trends for all months of the year. The most negative trend was for July ($Z = -3.18$). Also in the Lighvan station located at the upstream of the basin, annual discharge declined but its significance level is less than 10% ($Z = -1.03$). The river flow declined during the months of the year except for April and May, and the downward trend is significant from June to September. At the seasonal scale, there is also a downward trend in both stations for all four seasons; for the Hervy station, the downward trend level is significant for all the seasons, but in the Lighvan station only in summer is the level of the downward trend significant ($\alpha = 0.01$). Most of the climatic variables of the basin such as precipitation, temperature (mean, maximum, minimum, and difference of maximum–minimum), relative humidity, and evaporation were examined. The results showed that most of the temperature variables of the basin were increasing at different time scales (T_{mean} significant in winter and spring at 1% level, T_{max} significant in the year, winter and spring at 10% level). 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, while in the early part of the statistical period, significant rainfall occurred in the spring and affected the runoff of the basin. In the fall, despite the increasing trend of total precipitation, snow has decreased, and also heavy precipitation has declined, which is justifiable for runoff reduction. The trend of the relative humidity is generally negative (especially for February (Z is -1.54)), but the level of significance is low. The precipitation in winter and summer has generally a positive trend, each of which can have a separate interpretation, so that the increasing trend of precipitation variables in winter and summer may not have a positive role on runoff increasing due to the upward trend of

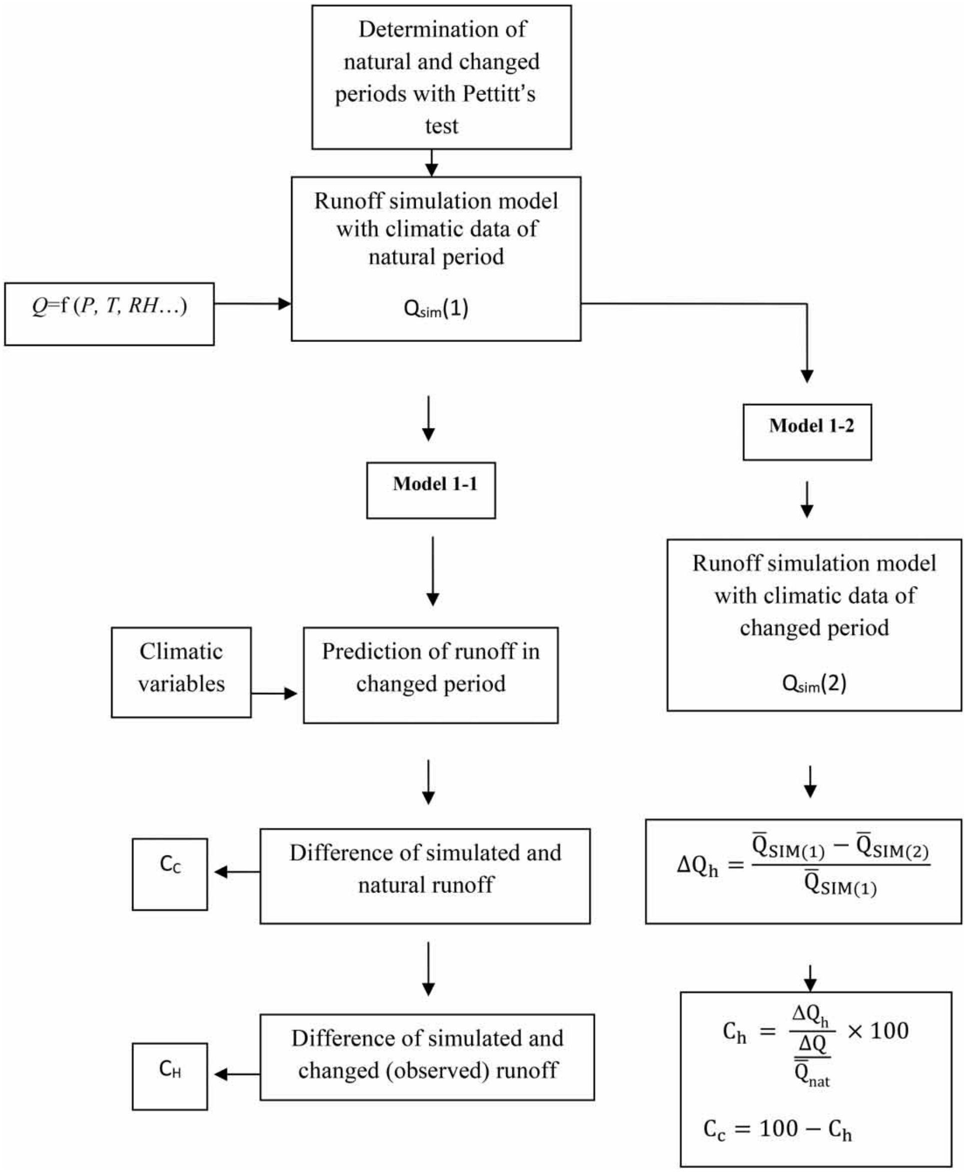

Figure 2 | Flowchart of two methods for determining the role of climatic and human factors.

temperature variables and reduction of the humidity. The results of the trend test for the seasonal and annual scales are presented in Table 3.

Studying the existence of change point in the studied time series using the Pettitt test (Table 4), it can be found that for the Hervy station, a change point is detected in 1995, and data of annual discharge were divided into two periods of 1970–1995 and 1996–2014. However, 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 3 shows the point changes of discharge in the upstream and downstream of the Lighvan basin. Comparison of the average discharge in the Hervy station in the two periods indicates a 36% decrease in the recent period (affected) compared to the natural period (first period). These changes are due to the combination of climatic factors and human activities in the basin.

Table 3 | Results of the Mann–Kendall test (*Z* values) for the hydroclimatic variables of Lighvan basin

Variable	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.

Table 4 | The Pettitt test results for the annual hydroclimatic variables in Lighvan basin

Variable	K	*P*-value	Change point (year)	Mean of 1st period	Mean of 2nd period
Q-Hervy (cms)	312	0.0004^{++}	1995	0.714	**0.460**
Q-Lighvan (cms)	110	0.934	–	–	–
P (mm)	206	0.049^{+}	2001	313.5	**389.8**
T_{mean} (°C)	241	0.014^{+}	1998	6.4	**7.5**
T_{max} (°C)	256	0.007^{++}	1993	12.5	**14**
T_{min} (°C)	238	0.016^{+}	1998	0.1	**1.2**
T_{max}-T_{min} (°C)	234	0.016^{+}	1978	10.9	**13.1**
RH (%)	244	0.012^{+}	2002	60.6	**53.5**
Snow (mm)	142	0.34	–	–	–

Note: Numbers with $^{+}$ and $^{++}$ signs are significant at 5% and 1%, respectively. *Q, P, T, RH*, and *Snow* are streamflow, precipitation, temperature, relative humidity, and sum of snowfall in year, respectively. *K* is change point calculated, and *Change point* is time of rapid change in series. *Mean of 1st period* and *Mean of 2nd period* is mean of variable in the first and second period, respectively.

Simulation of river flow

After determining the change point (the sudden change) of the studied parameters (particularly discharge data of basin) using the Pettitt test method, in order to predict the natural discharge (discharges generated without human effects) in the second (post-change) period, the regression model for the discharge data was developed using the climatic variables of the basin in the first period. Then, the discharge values of the second period were predicted based on the same climatic variables that affected runoff of the basin. In order to develop the regression models and select the best input variables among various annual and seasonal climatic variables (more than 20) in the first period, different combinations of the variables were considered as the model inputs (Table 5) and then the best ones were selected based on three statistical measures (Table 6). As it is seen from Table 6, in the forward method, in order to eliminate inflation of variance and overlap of the input variables, a large number of climatic variables were eliminated. The ridge regression method used most of the climatic variables that were effective on the generation of the runoff. In this method, the inflation of the variance obtained from the regressors is eliminated. The *model 1-1* is selected as the most suitable model for simulating the river flow based on high value of the R^2 (0.78) and

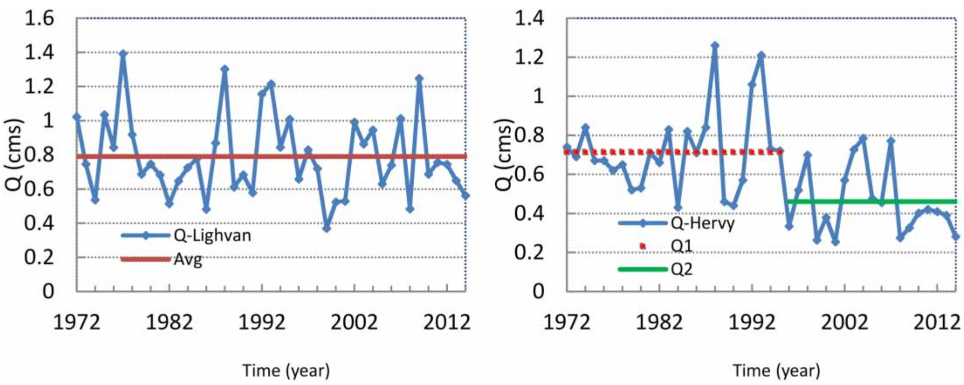

Figure 3 | Changes in annual discharge of the Lighvan River in the upstream (Lighvan station) and downstream of the basin (Hervy station).

Table 5 | A list of some combinations of the different input variables for models

Model	Input variables	R^2	RMSE
1	P, T_{mean}, RH, FD, $E7$, $\underline{Snow_{Year}}$, P_{Autumn}, P_{Winter}	0.75	0.131
2	P, T_{mean}, RH, FD, $E7$, P_{Autumn}, P_{Winter}	0.73	0.132
3	P, T_{mean}, RH, FD, $\underline{E7}$, P_{Autumn}, P_{Winter}, $Snow/P_{Spring}$	0.78	0.123
4	P, T_{mean}, RH, FD, $Snow_{Spring}$, P_{Autumn}, P_{Winter}	0.74	0.130
5	P, T_{mean}, RH, FD, $Snow/P_{Spring}$, P_{Autumn}, P_{Winter}	0.78	0.120
6	P, T_{mean}, RH, FD, $Snow/P_{Spring}$, P_{Autumn}	0.78	0.117
7	T_{mean}, RH, FD, $Snow/P_{Spring}$, P_{Autumn}	0.76	0.120
8	P, $\underline{T_{mean}}$, T_{max}, T_{min}, RH, FD	0.74	0.124
9	P, T_{mean}, $\underline{T_{max}}$, $\underline{T_{min}}$, RH, FD, $E7$, $\underline{Snow_{Year}}$, $Snow/P_{Spring}$, $T_{mean\text{-}Winter}$, $T_{max\text{-}Winter}$	0.90	0.126
10	P, $\underline{T_{mean}}$, T_{max}, T_{min}, RH, FD, $E7$, $\underline{Snow_{Year}}$, $T_{min\text{-}Winter}$, $T_{max\text{-}Winter}$, P_{Autumn}, P_{Winter}	0.81	0.134

Note: *E7* is the sum of evaporation in seven months (April–October). Variables that are underlined did not have logical coefficient.

Table 6 | Best input variables selected by three models based on statistical measures

Model	Input variables	R^2	*RMSE*	*NSE*
Model – forward	RH, $Snow/P_{Spring}$, P_{Autumn}	0.75	0.114	0.719
Model 1-1	P, T_{mean}, RH, FD, $Snow/P_{Spring}$, P_{Autumn}	0.78	0.117	0.781
Model 1-2	P, T_{mean}, RH, FD, $Snow/P_{Spring}$, P_{Autumn}	0.52	0.148	0.863

Note: *Model 1-1* and *Model 1-2* are derived from the ridge regression model for the first and second periods, respectively.

NSE (the Nash–Sutcliffe efficiency) and low value of *RMSE* (0.117). It is noteworthy that the choice of optimal model was not only based on the values of R^2 and *NSE*, but also the coefficients of the variables were considered so that there is logical and analytical relation between the runoff mechanism and the variables. That is, we know, for example, that the temperature has a negative effect on runoff and in cases where this parameter was positive, this model of choice was abandoned. For another new model called *model 1-2*, the regressor coefficients were obtained using the selected input variables and the same algorithms used in *model 1-1* for the second period.

The Guo model (Equation (8)), which was obtained during the first period and used for runoff prediction in the second period (affected period) is as follows:

$$Q_{sim(1)} = -0.549 + 0.0005P - 0.0274T_{mean} + 0.0109RH + 0.003FD + 1.765\,Snow/p_{Spring} + 0.0009P_{Autumn}$$

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

The simulated streamflow changes by the above model during the first period are shown in Figure 4. It can be seen from Figure 4(a) that the estimated values are quite close to the observed values. Runoff values of the basin were also predicted using the selected input variables for the second period at the Hervy station (Figure 4(c)). It can be found from Figure 4(c) that the estimated flows of the model indicate some errors, which can be due to the impact of human factors on streamflow.

The model which was obtained during the second period (affected period) is as follows:

$$Q_{sim(2)} = -0.232 + 0.001P - 0.024T_{mean} + 0.001RH + 0.002FD + 0.084Snow/P_{Spring} + 0.0001P_{Autumn}$$

The variables of the above equation are the same as those of equation $Q_{sim(1)}$.

In Figure 5, comparison of the observed and estimated discharge values of the *model 1-2* is shown over the total

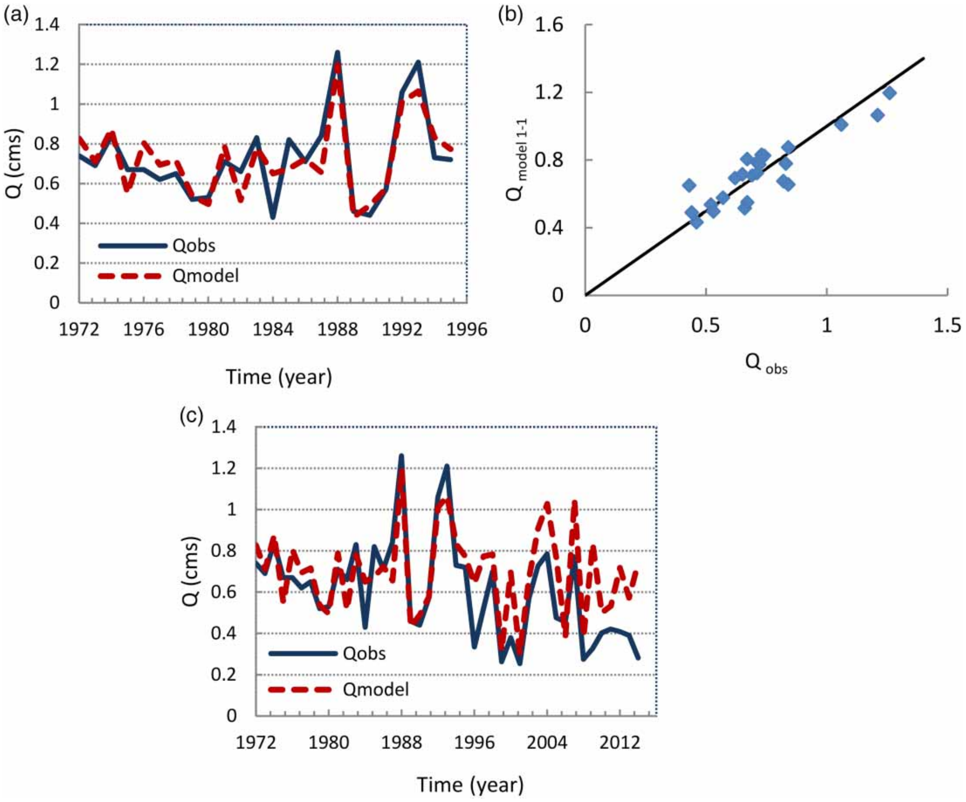

Figure 4 | Comparison of the observed and simulated flow values of the *model 1-1* in the first period (a) and in the total statistical period (c), scatterplot of the observed and simulated data in the first period (b).

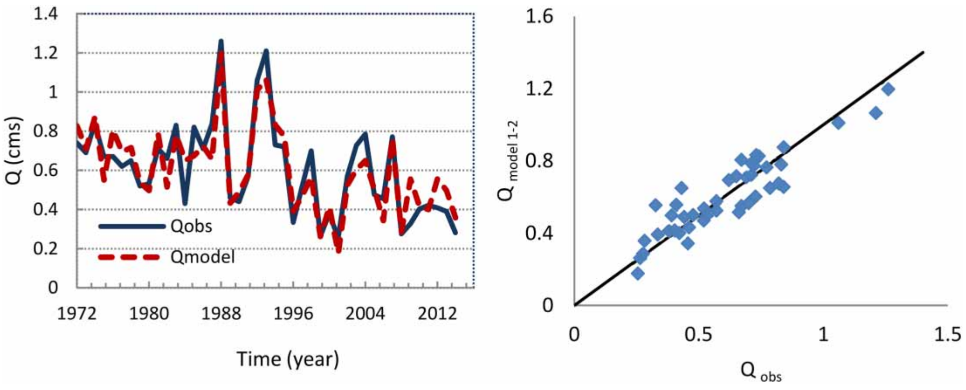

Figure 5 | Comparison of the observed and simulated discharge using the *model 1-2*.

statistical period. In fact, in this figure, the comparison values for the first period (1970–1995) are the same as in Figure 4(a), and the values for the second period (1996–2014) only have been changed. It can be seen from Figure 5 that the estimated discharges almost match the observed values. In this case, only the influence of the climatic factors has been introduced and the role of human factors has not been considered. In other words, the ratio of the difference between the two models to the average of simulated discharges derived from the first period model was considered as the concept of human changes.

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

The contribution of each of the climatic and human factors in reducing the discharge of the Lighvan River was calculated based on the relations presented in the Materials and methods section, for Hervy station (Table 7).

As is seen in Table 7, in the first method the contribution of climatic and human factors in reducing the runoff of the river is about 23% and 77%, respectively. For the second method, these values were 16% and 84%, respectively. The results showed that in both models, the contribution of climatic (16% and 23%) and human factors (77% and 84%) to the reduction of river discharges are quite close. 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 66%) was more than the climatic (about 34%).

DISCUSSION

Regarding the results obtained in the selected model for streamflow prediction, it can be seen that, first, the ridge regression method has better results compared with other regression methods and holds effective climatic parameters in the models that are also recognized as essential in physical analysis. Second, 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). While in some previous studies, such as those of Guo *et al.* (2014) and Tan & Gan (2015) and others, only the total annual precipitation (P) and PET were used and details of climatic factors have not been considered.

The results of the Mann–Kendall and Pettitt tests on the monotonic and rapid changes in river flow in the upstream and downstream of the basin showed that in the upstream of the basin (Lighvan station), although there was a monotonic downward trend there was no sudden change. 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. The study by Ye *et al.* (2013) in the Poyang basin in Yangtze also showed that river flow changes vary across the basin's different spatial locations.

Estimating the contribution of climatic and human factors in streamflow changes in the studied basin by using two models showed that the contribution of human factors is greater than climatic factors, and the results of both selected models are almost the same and have no significant difference. In some of the tested models in this study, which are not presented here, the contribution of climatic factors resulted in up to one-third of the total variation and two-thirds of the remainder 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 suggested to repeat this study in several other basins). Previous studies have also had different results in different basins. Hu *et al.* (2012) showed that the contribution of climatic and human factors is 38–40% and 60–62%, respectively. Results of the study by Zhan *et al.* (2014) were similar. Jiang *et al.* (2011) showed that the share

Table 7 | The results of the contribution of climatic and human factors in river flow reduction

Model	$\bar{Q}_{nat}$ (cms)	$\bar{Q}_{imp}$ (cms)	ΔQ (cms)	C (%)	$\bar{Q}_{sim(1)}$ (cms)	$\bar{Q}_{sim(2)}$ (cms)	ΔQ_h (cms)	C_c (%)	C_h (%)
Model 1-1	0.724	0.459	0.265	36.6	0.663	–	–	**23**	**77**
Model 1-2	0.724	0.459	0.265	36.6	0.663	0.459	0.307	**16**	**84**

of human factors in streamflow changes is 89–93%. In some of the studied basins, the effect of climatic factors on runoff was positive and human factors were negative which, in general, has reduced runoff (Zhao *et al.* 2015). 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 the studied region and the city of Tabriz in the basin area in 2000–2001, generally harvesting 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, Khalegi (2014) in a 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 and 2012. The area of good rangeland has decreased by 44%, and as a result, dry cultivation has increased by 38.6%.

It is necessary to explain the limitations of the empirical model compared to processed-based hydrological models. Empirical input–output 'black-box' models simply attempt to relate precipitation or other variables as input to streamflow as output, with little or no regard to the individual hydrological processes involved. Conceptual models, on the other hand, attempt to simulate, to a greater or (usually) lesser extent, the most important perceived hydrological mechanisms of the catchment response to rainfall, e.g., interception, evapotranspiration, infiltration, and both groundwater and surface water flow routing, etc. Thus, while distributed physically based models are undoubtedly more scientific than the other two model types, their application in operational flood forecasting systems is not yet widespread due to their inherent complexity, their extensive data demands and costs. The conceptual models, particularly in their semi-lumped and semi-distributed forms, have more potential than the black-box models. Conceptual models have some potential for predicting the effects, for example, land use change or for application to ungauged catchments. However, even simple parametric black-box models can also be used for investigating relations between parameters and the catchment characteristics (Connor 2005).

It should be noted that the estimates using the models in this research have uncertainties, including possible errors in the data used. Also, it is possible that part of the difference in the estimated flow in the two periods (natural and influenced) is related to model error. However, these uncertainties do not seem to have a significant impact on the overall conclusion.

CONCLUSION

In this study, the reasons for the runoff changes in the Lighvan River, Iran were identified, and the effect of the influencing factors, climatic and human factors, on runoff reduction were determined. The results of the trend analysis of the Lighvan River flow showed a decreasing trend in most of the time scales, and examination of the climatic factors indicated that there was an increase in the temperature values and a decrease in the relative humidity values at the basin. It was found by results of the Pettitt test that the time of change point for most variables used in the study is the 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 greater 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 water resources and environment protection.

REFERENCES

Connor, K. 2005 River flow forecasting. In: *River Basin Modelling for Flood Risk Mitigation* (D. Knight & A. Shamseldin, eds). Taylor & Francis Group, London, UK, pp. 197–210.

Gao, P., Geissen, V., Ritsema, C. J., Mu, X. M. & Wang, F. 2013 Impact of climate change and anthropogenic activities on stream flow and sediment discharge in the Wei River basin, China. *Hydrology and Earth System Sciences* **17**, 961–972.

Guo, Y., Li, Z., Boateng, M. A., Deng, P. & Pengnian, H. 2014 Quantitative assessment of the impact of climate variability and human activities on runoff changes for the upper reaches of Weihe River. *Stochastic Environmental Research and Risk Assessment* **28** (2), 333–346.

Guo, A., Huang, Q. & Wang, Y. 2015 Quantitative study of impacts of climate change and human activities on runoff in Beiluohe River basin. *Remote Sensing and GIS for Hydrology and Water Resources* **368**, 263–268.

Hamed, K. H. & Rao, A. R. 1998 A modified Mann-Kendall trend test for autocorrelated data. *Journal of Hydrology* **204**, 182–196.

Hood, M. 2011 Increased flooding driven by climate change. African Network of Environmental Journalists (ANEJ). https://phys.org/news/2011-02-driven-climate.html (accessed 16 February 2011).

Hu, S., Zheng, H., Wang, Z & Yu, J. 2012 Assessing the impacts of climate variability and human activities on streamflow in the water source area of Baiyangdian Lake. *Journal of Geographical Sciences* **22** (5), 895–905.

Jiang, S., Ren, L., Yong, B., Singh, V. P., Yang, X. & Yuan, F. 2011 Quantifying the effects of climate variability and human activities on runoff from the Laohahe basin in northern China using three different methods. *Hydrological Processes* **25** (16), 2492–2505.

Jones, R. N., Chiew, F. H. S., Boughton, W. C. & Zhang, L. 2006 Estimating the sensitivity of mean annual runoff to climate change using selected hydrological models. *Advances in Water Resources* **29** (10), 1419–1429.

Kendall, M. G. 1975 *Rank Correlation Methods*. Griffin, London, UK.

Khalegi, S. 2014 *The Evaluation of Morphologic Changes of River in Drainage Basins in Response to Land use Changes (Case Study: Lighvan Chai Catchment)*. PhD thesis, University of Tabriz.

Li, L., Zhang, L., Wang, J., Yang, J., Jiang, D., Li, J. & Qin, D. 2007 Assessing the impact of climate variability and human activities on streamflow from the Wuding River basin in China. *Hydrological Processes* **21**, 3485–3491.

Li, F., Zhang, G. & Xu, Y. 2014 Separating the impacts of climate variation and human activities on runoff in the Songhua River Basin, Northeast China. *Water* **6**, 3320–3338.

Ma, H., Yang, D., Tan, S., Gao, B. & Hu, Q. 2010 Impact of climate variability and human activity on streamflow decrease in the Miyun Reservoir catchment. *Journal of Hydrology* **389** (3–4), 317–324.

Mann, H. B. 1945 Non-parametric tests against trend. *Econometrica* **33**, 245–259.

Okhravi, S., Eslamian, S. & Tarkesh Esfahany, S. 2017 Drought in Lake Urmia. In: *Handbook of Drought and Water Scarcity: Environmental Impacts and Analysis of Drought and Water Scarcity* (S. Eslamian & F. Eslamian, eds). CRC Press, Boca Raton, FL, USA, pp. 605–618.

Parks, B. & Madison, R. J. 1985 *Estimation of Selected Flow and Water-Quality Characteristics of Alaskan Streams*. (No. WRI-84-4247). United States Geological Survey, Reston, VA, USA.

Pettitt, A. N. 1979 A non-parametric approach to the change point problem. *Applied Statistics* **28** (2), 126–135.

Tan, X. & Gan, T. Y. 2015 Contribution of human and climate change impacts to changes in streamflow of Canada. *Scientific Reports* **5**. doi:10.1038/srep17767.

Vaze, J., Post, D. A., Chiew, F. H., Perraud, J. M., Viney, N. R. & Teng, J. 2010 Climate non-stationarity – validity of calibrated rainfall–runoff models for use in climate change studies. *Journal of Hydrology* **394** (3–4), 447–457.

Wang, D. & Hejazi, M. 2011 Quantifying the relative contribution of the climate and direct human impacts on mean annual streamflow in the contiguous United States. *Water Resources Research* **47**, W00J12. doi:10.1029/2010WR010283.

Wang, H., Chen, L. & Yu, X. 2016 Distinguishing human and climate influences on streamflow changes in Luan River basin in China. *Catena* **136**, 182–188.

Ye, X., Zhang, Q., Liu, J., Li, X. & Xu, C. 2013 Distinguishing the relative impacts of climate change and human activities on variation of streamflow in the Poyang Lake catchment, China. *Journal of Hydrology* **494**, 83–95.

Zhan, C. S., Jiang, S. S., Sun, F. B., Jia, Y. W., Niu, C. W. & Yue, W. F. 2014 Quantitative contribution of climate change and human activities to runoff changes in the Wei River basin, China. *Hydrology and Earth System Sciences* **18**, 3069–3077.

Zhang, Y., Guan, D., Jin, C., Wang, A., Wu, J. & Yuan, F. 2011 Analysis of impacts of climate variability and human activity on streamflow for a river basin in northeast China. *Journal of Hydrology* **410** (3–4), 239–247.

Zhao, C., Liu, C., Dai, X., Liu, T., Duan, Z., Liu, L. & Mitrovic, S. M. 2015 Separation of the impacts of climate change and human activity on runoff variations. *Hydrological Sciences Journal* **60** (2), 234–246.

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