Contribution of climatic variability and human activities to stream flow changes in the Haraz River basin, northern Iran

Abdollah Pirnia[a*], Hamid Darabi[b], Bahram Choubin[a], Ebrahim Omidvar[c], Charles Onyutha[d], Ali Torabi Haghighi[b]

[a] Department of Watershed Management Engineering, Sari Agriculture Science and Natural Resources University, P.O. Box, 737, Sari, Iran.

[b] Water, Energy and Environmental Engineering Research Unit, P.O. Box 4300, FIN-90014 University of Oulu, Finland.

[c] Department of Range and Watershed Management, Faculty of Natural Resources and Earth Sciences, University of Kashan, Iran

[d] KU Leuven, Hydraulics Laboratory, KU Leuven, Kasteelpark Arenberg 40, 3001 Heverlee, Belgium.

* Corresponding author

https://doi.org/10.1016/j.jher.2019.05.001

Contribution of climatic variability and human activities to stream flow changes in the Haraz River basin, northern Iran

Abstract

In northern Iran's Haraz River basin between 1975 and 2010, hydrological sensitivity, double mass curve, and Soil and Water Assessment Tool (SWAT) methods were applied to monitoring and analysing changes in stream flow brought on by climatic variability and human activities. Applied to analyse trends in annual and seasonal runoff over this period, the sequential MK test showed a sudden change point in stream flow in 1994. The study period was, therefore, divided into two sub-periods: 1975-1994 and 1995-2010. The SWAT model showed obvious changes in water resource components between the two periods: in comparison to the period of 1975-1994, sub-watershed-scale stream flow and soil moisture decreased during 1995-2010. Changes in evapotranspiration were negligible compared to those in stream flow and soil moisture. The hydrological sensitivity method indicated that climatic variability and human activities contributed to 29.86% and 70.14%, respectively, of changes in annual stream flow, while the SWAT model placed these contributions at 34.78% and 65.21%, respectively. The double mass curve method indicated the contribution of climatic variability to stream flow changes to be 57.5% for the wet season and 22.87% for the dry season, while human activities contributed 42.5% and 77.13%, respectively. Accordingly, in the face of climatic variability, measures should be developed and implemented to mitigate its impacts and maintain eco-environmental integrity and water supplies.

Keywords: Trend analysis; Climatic variability; Anthropogenic activities; SWAT model; water balance; Annual and seasonal stream flow; Haraz River basin

1. Introduction

Stream flow is a vital part of the study of water resources. Quality and quantity of flow is highly affected by climatic variability and human activities, *e.g.*, land use changes, irrigation, reservoir construction, etc. (Wu et al., 2013; Pirnia et al., 2014; Darabi et al., 2014: Tan and Gan, 2015; Ahn and Merwade, 2017; Torabi Haghighi et al., 2018). Global temperature raised by 0.89°C from 1901 until 2012 and is predicted to further increase in the 21st century. This increase may lead to significant changes in precipitation and runoff (IPCC, 2013; Qin et al., 2014). In addition, increasing population and greater water and food requirements have led to greater demands on water resources (Cheng et al., 2016; Tian et al., 2016). Hydrological responses of basins to climate change and variability differ throughout the world. In some regions, significant changes in temperature and precipitation have resulted in greater base flow, annual mean discharge and flooding (Ahn et al., 2016). In other areas, however, base flow has declined along with annual mean discharge, and drought conditions have prevailed (Dai, 2013; Zhao et al., 2015; Wang et al., 2016; Sadegh et al., 2018). In general, over recent years, Iran has seen a decrease in precipitation and stream flow and an increase in the occurrence of drought (Menberu et al., 2014; Khoshravesh et al., 2016; Ghasemi and Moogooei, 2017; Mousavi and Marofi, 2017). Destruction of land cover and decreased precipitation in northern Iran, have led to flood and drought events, respectively (Ghanghermeh and Roshan, 2015; Arab Ameri, 2017).

Hydrologists have recently shown increased interest in trend analysis of river flows and the identification of driving factors. While a few studies focused specifically on either the contribution of human activities (Gao et al., 2014) or the impact of climatic factors (Li et al., 2012; Song et al., 2014) on stream flow changes, many considered both (Zhang et al., 2012; Cheng et al., 2016; Ashraf et al., 2016; Zhang et al., 2016; Zhang et al., 2017; Torabi Haghighi, and Kløve, 2017; Fazel et al., 2017). Cheng et al. (2016) reported that changes in precipitation during 1971-1994 and 1995-2008 led, respectively, to 33.3% and 48.9% declines in runoff, and 3.8% and 17.1% declines in the river's sediment loads within the Yanhe River basin. They concluded that the contribution of human activities exceeded that of climatic variability. Zhang et al. (2017) concluded that anthropogenic activities (*e.g.*, use of ground and surface water for urbanization, industrialization and the creation of reservoirs) contributed 63-65% to recent drought events in the Haihe River basin.

The extent to which stream flow is driven by climatic variability and human activities is generally evaluated through time series analysis, elasticity-based methods or hydrological modelling. Providing useful options in determining runoff responses to drivers such as climatic changes and human actions, statistical methods draw on relationships between hydro-meteorological variables (e.g., stream flow and a climatic variable like precipitation), and identify the contribution of effective factors to changes in stream flow (Zhang et al., 2014; Torabi Haghighi et al., 2016). Hydrological data time series (*e.g.*, stream flow series) show temporal oscillations caused by climate and land use changes and can serve to identify runoff changes due to either change in climate or human activities (Zhang et al., 2011). In elasticity-based methods, stream flow alterations arising from climate variability are detected on the basis of stream flow sensitivity to precipitation and potential evapotranspiration (ET_{pot}).

A better understanding of the impacts of effective drivers on stream flow changes can be achieved through the application of multiple approaches rather than a single approach. In the present study three methods were applied: a double mass curve time series analysis method, a hydrological sensitivity elasticity-based method, and a comprehensive hydrological model (SWAT). Stream flow is influenced by both climatic variability and human activities, it is, therefore, essential to separate the influence of these two drivers to allow for sound policy decisions and proper management of water resources.

Although the destruction of natural resources in northern Iran has increased considerably in response to population growth and increased demands for water, soil and food resources over recent decades (Mirakhorlou and Akhavan, 2016; Darabi et al., 2019), this region still maintains the densest vegetation cover in the country. As a result of these challenges, and the sensitivity of Iran's northern basins to variations in runoff, the most destructive of Iran's recent floods have occurred in the northern basins (Rahimi, 2016). Accordingly, a complete study of these basins' water resource components is necessary to improve management decision-making in this area.

The present study was specifically aimed at: (*i*) understanding trends and identifying any sudden change of the annual and seasonal runoff; (*ii*) separating climatic variability and human activities contributions in annual and seasonal stream flow changes; and (*iii*) evaluating the spatio-temporal changes of hydrological components in the basin and sub-basins. This study was unique as it represented an effort to: (*i*) identify the individual impacts of climatic change and human activities to stream flow in both pre- and post-break point periods; and (*ii*) detect relevant water resources components before and after the abrupt change. In order to confirm these results, the SWAT model was applied under two different scenarios: (*a*) varying climate under constant land use, and (*b*) constant climatic conditions under shifting human activities. Differences in simulated values were deemed a climate variability effect, whereas the proportion of the difference in observed values to the difference in the simulated values (climate variability contribution), was deemed to represent the impacts of human activities.

2. Study Area

Located in northern Iran (39° 23´- 40° 15´N lat., 53° 90´- 63° 22´E long.), the Haraz River basin drains an area of approximately 4,014 km^2 and varies in elevation from 300 m to 5600 m (Fig. 1). Annual precipitation ranges from 302 mm in the central region (Panjab station) to 1,069 mm in the eastern region (Ghoran Talar station) with a mean annual precipitation of 685 mm across the basin. Annual mean temperature varies from 5°C in Firouzkouh to 23.1 °C at the Rineh station, with a basin average of 13°C. Most land cover of the Haraz basin consists of high-density grassland. The north-eastern part of the basin has high-density and semi-dense forests. Dominant land use categories along rivers include irrigated lands and orchards. There are numerous rivers in the basin, but the Haraz River has the largest water supply in the north of Iran and the largest river in the Caspian Sea basin, with an average discharge of 31.1 $m^3 s^{-1}$.

In the Haraz River some activities including mining, road construction, and expansion of barren and urban lands had huge impacts in recent years. Zargoosh et al. (2014) found that forest and grassland areas decreased, and barren lands and orchards increased between 1988-2013. Namdar et al. (2013) showed that river flow will likely decrease considerably in the future as a result of climate change. However, it remains important to more fully understand the possible changes in water resources that can be attributed to climate variability and human activity.

Urbanization and also population growth can affect watershed hydrological responses (Lee et al., 2017), and currently most watersheds in developing countries (especially Iran) are experiencing large population growth along with the expansion of impervious area. Fig. 2 shows the change in population and impervious area in the Haraz river basin. Specifically, Fig. 2a shows that the population in the Haraz river basin increased during 1972–2012 while Fig. 2b shows the dramatic increase of impervious area caused by urban and rural development during 1983–2013 in the in the Haraz river basin. Therefore, both climate and human drivers affect the hydrological responses in the Haraz river basin.

Figure 1:

Figure 2:

3. Materials and Methods

3.1. Data and study period

3.1.1. Hydro-meteorological data

The monthly runoff data (1975-2010), from the Karesang hydrological station on the Haraz River and monthly precipitation, solar radiation, maximum and minimum temperatures, and humidity data of 1975–2010 period were used from 16 climate stations, within and around the study basin (Table 1). The ET_{pot} data were estimated by the Penman-Monteith method (Allen et al., 1998; Huang et al., 2014). As precipitation varies in intensity and duration throughout the entire basin, the basin-averaged precipitation and ET_{pot} were computed using the Thiessen polygon method.

3.1.2. Geospatial data:

Spatial data, including a digital elevation model (DEM) along with land use (produced by Landsat images) and soil map (1:100000), were used to set up and run the SWAT model, which was then calibrated and validated for the estimation of the water balance (Table 1). Land use maps were obtained from 1991, 2006 and 2013 Landsat satellite data (United States Geological Survey; USGS). The DEM data, at a 30-m resolution, was used to calculate sub-basin physiographic parameters.

Table 1:

Quantifying and understanding stream flow changes using an intra-annual scale (i.e., seasonal or monthly) can provide more significant information than if inter-annual time scales are used (Wang et al., 2016), the latter, however, is still most commonly used. The analysis of annual runoff does not reveal the reasons for stream flow change in any detail. Hence, the assessing the seasonal flows caused by of climate variability and human activities can represent a more important analysis in terms of understanding the effective factors contributing to stream flow changes (Zhang et al., 2016). Changes in stream flow resulting from climate variability and human activities at a seasonal scale may be more important than those occurring on an inter-annual scale. To better understand stream flow changes according to the specific characteristics of precipitation in the Haraz River basin, annual stream flow was divided into two temporal intervals: May to September (dry period) and October to April (wet period).

3.2. Trend analysis

Statistical methods designed to analyse trends in time series (parametric or non-parametric), with the latter having more extensive applications (Xu et al., 2015).

3.2.1. Mann-Kendall (MK) trend test

The Mann-Kendall (MK) test (nonparametric methods) are widely used for hydro-climatological purposes (Zhang et al., 2012; Chen et al., 2013; Ahn and Palmer, 2015; Pirnia et al., 2018) and t is a distribution-free method for trend analysis with minimal assumptions for time series. In the present study MK test was applied to determine the trends in the observed and modelled hydro-climatological data.

3.2.2. Determination of change point using the sequential MK and Pettitt tests

A sequential MK test is used to detect an sudden change point. The test statistic S_k is calculated as (Wang et al., 2016):

$$S_K=\sum_{i=1}^{k}\sum_{j=1}^{i-1} a_{ij}(k=2,3,4,\ldots,n) \quad (1)$$

$$\alpha_{ij}=\begin{cases}1 & x_i>x_j\\ 0 & x_i\leq x_j\end{cases} \quad \text{where } 1\leq j\leq i \quad (2)$$

The statistical index, UF, is then calculated as (Xu et al., 2015):

$$\mathrm{UF}=\frac{S_k-E(S_k)}{\sqrt{Var(S_k)}} \quad \text{where } k=1,2,3,\cdots,n \quad (3)$$

where,

$$E(S_k)=\frac{k(k-1)}{\sqrt{Var(S_k)}} \quad (4)$$

$$Var(S_k) = \frac{k(k-1)(2k=1)}{72} \quad (5)$$

The UF and UB, namely the statistical indices for a forward and backward sequence, follow a standard normal distribution and are computed by the same equation, but with their time series running inversely.

3.3. Impacts of climate variability and human activities on stream flow

3.3.1. Hydrological sensitivity method

Water

Long-term water balance can be assessed the effects of climate variability on runoff and it can be summarized as follow (Lee and Kim, 2017):

$$P = E + Q + \Delta S \quad (6)$$

where *P* is the precipitation (mm), *Q* is the runoff (mm), and Δ*S* is the water storage change in watershed and *E*, a a function of the dryness index ϕ=*E*o/*P*, is the actual evapotranspiration (mm). The actual evaporation (*E*), was calculated based on six popular Budyko-based functions (Table 2) and Eq. 7.

Table 2:

$$E = PF(\emptyset) \quad (7)$$

A hydrological sensitivity method was applied to determine stream flow modifications, driven by changes in rainfall and potential evapotranspiration, as the climatic variables affecting stream flow (Wang et al., 2016). According to this method, mean annual stream flow change was calculated by Eq. 8 (Li et al., 2007; Ahn and Merwade, 2014):

$$\Delta Q^{clim} = \beta \Delta P + \gamma \Delta E_0 \quad (8)$$

where, ΔQ^{clim} is the stream flow change influenced by climate variability, and ΔP and ΔE_0 are precipitation and ET_{pot} changes, respectively. The values of β and γ are stream flow sensitivity to precipitation and ET_{pot}, respectively, and are calculated as (Wang et al., 2016; Lee and Kim, 2017):

$$\beta = \frac{1 + 2\eta + 3\omega\eta^2}{(1 + x + \omega\eta^2)^2} \tag{9}$$

$$\gamma = \frac{1 + 2\omega\eta}{(1 + x + \omega\eta^2)^2} \tag{10}$$

Where, η and ω are the dryness index (equivalent to ET_{pot}/P) and plant-available water coefficient, respectively. The term ω represents the relative difference in the way plants use soil water for transpiration.

3.3.2. Methodology for hydrological separation

The double mass curve method uses stream flow and cumulative rainfall values to determine the start time of obvious changes in stream flow resulting from anthropogenic activities (Searcy and Hardison, 1960). This method has been extensively applied to assess the consistency between hydro-meteorological time series and, in particular, to detect stream flow changes attributable to the impacts of human activity (Wang et al., 2016; Gao et al., 2013). Contribution of these impacts, compared with precipitation as the important climatic factor, is determined by the double mass curve. The rationale is that digression of a linear relationship between cumulative stream flow and precipitation should show the impact of human activities (Wang et al., 2016). Runoff variation is related to the climate variability impacts and human activities. Accordingly, the total variation in runoff, ΔQ^{tot}, is calculated as (Peng et al., 2016):

$$\Delta Q^{tot} = \Delta Q^{hum} + \Delta Q^{clim} \tag{11}$$

where, $\Delta Q^{clim}$and ΔQ^{hum} are the runoff changes caused by climate variability and human activities, respectively. Therefore, the proportion of ΔQ^{clim} in ΔQ^{tot} as well as the proportion of ΔQ^{hum} in ΔQ^{tot} are equal to the contribution of climate variability and human activity effects on the stream flow changes. The total variation in runoff can also be calculated as:

$$\Delta Q^{tot} = Q_2 - Q_1 \tag{12}$$

Where, Q_2 and Q_1 are the annual mean observed stream flow in the change and reference periods, respectively. Furthermore, separate analyses of the impacts of human activities and climate variability on runoff, C^{clim} and C^{hum}, respectively, can be estimated as (Bao et al., 2012):

$$C^{hum} = 100 \cdot \frac{\Delta Q^{hum}}{\Delta Q^{tot}} \qquad C^{clim} = 100 \cdot \frac{\Delta Q^{clim}}{\Delta Q^{tot}} \tag{13}$$

The double mass curve method is based on the linear regression evaluation. In the reference period the relationship between cumulative stream flow and rainfall is accordingly considered as (Peng et al., 2016):

$$\sum Q = k \sum P + b \tag{14}$$

Where, Q and P are stream flow and precipitation, respectively, and k and b are two coefficients. This equation is used to predict stream flow in the modified period. Considering precipitation, as the climate factor, is the same for both predicted and observed runoff, during the reference and change periods (in this study precipitation for the reference period was considered for the change period), the difference between observed and simulated values of stream flow during the change period is equal to the values influenced by human activities:

$$\Delta Q^{hum} = Q_2' - Q_2 \tag{15}$$

where, Q_2' is the annual mean predicted stream flow during the change period. Thus, the runoff change influenced by climate variability is the difference between the total runoff change and the runoff change caused by human activities (Fig. 3).

Figure 3:

3.3.3. Hydrologic modelling (SWAT model)

The semi-distributed SWAT model (Neitsch et al, 2011; Ahn and Merwade, 2014) was used to evaluate water flow components as well as to detect climate variability and human activity effects. SWAT simulations divide a basin into many hydrological response units (HRUs), all with uniform cover, soil and management regimes (Neitsch et al., 2011). Using small units for simulation purposes is very useful in situations where the basin has widely varying soil types and different land uses, which each affect basin hydrology differently. The water balance equation for detection of the hydrological components in SWAT is expressed as (Arnold et al., 1998; Zhang et al., 2016):

$$SW_t = SW_0 + \sum_{i=1}^{t}\left(P_i - ET_i - Q_{i,seep} - Q_{i,surf} - Q_{i,gw}\right) \quad (16)$$

where, SW_t is soil moisture at time *t* (mm); SW_0 is initial soil moisture (mm); *i* is the day counter; P_i is precipitation (mm); ET_i is evapotranspiration (mm); $Q_{i,seep}$ is percolation through the soil profile (mm); $Q_{i,surf}$ is surface runoff (mm); and $Q_{i,gw}$ is ground water return flow (mm).

In the present study, the first two years (1975-1976) were the warm-up period, while 1977-1985 and 1986-1994 were the calibration and validation periods, respectively, when stream flow was less heavily influenced by human activities.

3.3.4. SWAT model evaluation

The SWAT-CUP and SUFI-2 algorithms (Abbaspour, 2007; Abbaspour, 2011; Abbaspour et al., 2015) were used for calibration, validation, sensitivity and uncertainty analysis. After the sensitivity analysis, model accuracy was evaluated using the Nash-Sutcliffe Efficiency (NSE) criterion (Nash and Sutcliffe, 1970) and the coefficient of determination (R^2). The NSE and R^2 values range from -∞ to 1 and 0 to 1, respectively; generally acceptable values are higher than 0.5 and 0.6, respectively (Zhang et al., 2016):

$$NS = 1 - \left[\frac{\sum_{i=1}^{n}(Q_i^{0bs} - Q_i^{sim})^2}{\sum_{i=1}^{n}(Q_i^{obs} - \overline{Q_{obs}})^2}\right] \quad (17)$$

$$R^2 = \frac{\left[\sum_{i=1}^{n}\left(Q_i^{sim} - \bar{Q}_i^{sim}\right)\left(Q_i^{obs} - \bar{Q}_i^{obs}\right)\right]^2}{\sum_{i=1}^{n}\left(Q_i^{sim} - \bar{Q}_i^{sim}\right)^2 \sum_{i=1}^{n}\left(Q_i^{obs} - \bar{Q}_i^{obs}\right)^2} \quad (18)$$

where, Q_i^{obs} is the observed discharge, Q_i^{sim} is the simulated discharge, $\bar{Q}_i^{obs}$ is the average observed discharge, and $\bar{Q}_i^{sim}$ is the average simulated discharge ($m^3\ s^{-1}$).

The SUFI2 algorithm for determining the 95% prediction uncertainties (95PPU) generates two indices: the *p*-factor and the *r*-factor (Abbaspour, 2008). Defined as the percentage of obtained modelled data bracketed by the 95 PPU, the *p*-factor ranges from 0 to 1. The *r*-factor shows the quality of the simulation by expressing the average thickness of the 95PPU, values range between 0 and ∞. Ideally, both the *p*- and *r*-factors should be close to 1.0.

4. Results and Discussion

4.1. Annual stream flow trends and sudden change point

The null hypothesis H_0 (no trend) was rejected ($p \leq 0.05$) as the absolute values of all MK test standardized trend statistics exceeded 1.96 (Table 3). This indicates a negative trend for all series.

The results of both MK and Pettitt change point tests indicated a sudden change in the annual stream flow in 1994 ($p \leq 0.05$); as indicated by the intersection of the curves in Fig. 4. Based on this change point, the 1975-2010 series was divided into two periods: reference (1975-1994) and change (1995-2010) (Table 4). The negative value of UF confirmed a downward trend in annual stream flow, reflecting a considerable (43.4%) drop in mean annual stream flow; 212 mm to 120 mm between the reference and change periods, respectively (Table 5).

Table 3:

Figure 4:

Table 4:

Table 5:

4.2. Impacts of climatic variability and human activity on annual stream flow

4.2.1. Annual stream flow changes based on the hydrological sensitivity method

Table 5 also shows changes in ET_{pot} and precipitation between the reference and change periods. Annual precipitation decreased by 13.37% and temperature increased by 4.8%, while ET_{pot} increased only very slightly. Changes in climatic variables can have offsetting or synergistic impacts on water resource components (Shrestha et al., 2017), and in this case, it seems the changes in precipitation and temperature had offsetting effects on $\mathrm{ET_{pot}}$. It can be concluded accordingly that the basin was moving toward drier conditions.

The negligible change in $\mathrm{ET_{pot}}$ suggested that it had little effect on changes in runoff. Precipitation, however, had a greater effect on stream flow change within the Haraz River basin (Table 5) (Wang et al., 2015). Accordingly, Eq. 16 can be rewritten as:

$$\Delta Q^{clim} = \beta \Delta P \tag{19}$$

Sun et al. (2005) showed that in basins with complex land use types, the runoff sensitivity to changes in precipitation (β) can be described as:

$$\beta = \sum (\beta_i \cdot f_i) \tag{20}$$

where, f_i includes the area of land use types such as forest, grassland, farmland, construction and urban lands, etc. The ω values for the calculation of β (Eqs. 17 and 28) were set equal to 2, 1, 0.5, 1 and 0.1 for high-density forest (forest cover > 30%), low-density forest (forest cover < 30%), grassland and farmland, shrub land, urban and barren lands, respectively (Sun et al., 2006; Wang et al., 2016).

Based on land use maps of the Haraz River basin in 1988, 2000 and 2013, the proportion of total area under different land uses are shown in Table 6. Using Eq. 17 and Eq. 28, the value of β was found to be 0.335. Based on Eq. (27) and the decrease in stream flow of 92 mm y^{-1} between reference and change periods, the stream flow change was 29.85% (27.47 mm) by ΔQ^{clim} and 70.15% (64.53 mm) by ΔQ^{hum} (Table 7).

Table 6:

Table 7:

4.2.2. Parameter sensitivity, calibration and validation analysis

Analysis of sensitivity is extremely useful for identifying influential parameters and improving the SWAT model's simulation performance. The SUFI-2 algorithm detected 11 parameters that were sensitive to stream flow in the Haraz basin (Table 8). The most sensitive of these parameters were

CN2, ALPHA_BNK and CH_K2, indicating that stream flow in the Haraz basin was strongly influenced by snow, ground water, vegetation and soil properties.

The MK test and the identification of a sudden change point (1994), showed that data for calibration and validation periods were both drawn from before 1994, when stream flow was minimally influenced by human activities. The first two years (1975-1976) were considered a warm-up period, while 1977-1985 and 1986-1994 data served as calibration and validation periods, respectively. Visual and statistical evaluations of model performance are shown in Fig. 5 and Table 9. The R^2 and NSE values for calibration were 0.89 and 0.79, respectively, while the *p*-factor and *r*-factor values were 0.78 and 0.96, respectively. Although the performance for the calibration period was better than that for the validation period, based on a sufficiently narrow 95PPU band, the uncertainty for stream flow simulation in both periods was deemed relatively small. Thus, model simulation performance was considered acceptable.

Table 8:

Figure 5:

Table 9:

4.2.3. Investigation of flow component changes

Based on observed and SWAT-simulated stream flow values, stream flow amounts decreased by 92 mm and 32 mm, respectively, between the reference and change periods (Table 10). Climatic variability and human activities contributed 34.78% and 65.22%, respectively, to these changes. This indicates a greater importance of human activities. The results of hydrological sensitivity method and the SWAT model were similar, confirming the fact that human activities contributed more to changes in stream flow than climatic variability. These results are consistent with a number of other studies (Ahn and Merwade, 2014; Wang et al., 2016; Yan et al., 2017).

Table 10:

Runoff, ET, ground water and soil moisture were evaluated in the 1975-1994 and 1995-2010 periods to identify climate variability and land use change effects on flow components. Differences in flow components between the two periods were rather minor under land use change and constant precipitation and temperature conditions (Table 11). Runoff increased by 4.98%, and ET, ground water and soil moisture decreased by 0.93%, 2.7% and 7.14% respectively. In contrast, under constant land use conditions, climate variability had a much greater effect on flow components, such that ET, runoff, ground water and soil moisture values decreased by 3.96%, 28.29%, 15.2% and 11.76%, respectively, between reference and change periods.

A comparison of the results of the hydrological sensitivity method and SWAT model (Table 10) with the present (Table 11**)** confirms that land use change has a minimal effect on runoff. Human activities, excluding land use change, clearly had a considerable influence on the decrease in runoff in the Haraz River basin. Some studies, for example, reported the important role of regulative reservoirs on stream flow change (Song et al., 2015; Wang et al., 2016).

Table 11:

4.2.4. Spatial distribution of water resource components

The SWAT model was run with the basin divided into 19 sub-watersheds. Spatial distribution of runoff, ET and soil moisture are shown in Fig. 6 for the 1975-1994 and 1995-2010 periods.

Figure 6:

4.2.4.1. Spatial distribution of stream flow

The highest stream flows occurred in the downstream sub-watersheds, and the lowest in the central regions of the basin (Fig. 6). Although downstream areas of the basin included dense and semi-dense forest, high runoff values still occurred in these regions due to high precipitation compared to other regions, and strong stream flow recharge by groundwater driven by snowmelt in the central and southern sub-watersheds.

The stream flow for the 1995-2010 period was considerably reduced in most sub watersheds, especially in the northern and downstream areas. This illustrated the importance of climate variability compared with land use change. The decreased runoff caused by lower precipitation overcame the increased runoff caused by less forest and rangeland and more barren and urban areas.

4.2.4.2. Spatial distribution of evapotranspiration

The highest ET values occurred in downstream and northern sub-watersheds, while the lowest ET occurred in the central and western sub-watersheds (Fig. 6). Forest and rangeland land use types in downstream sub-watersheds along with high temperatures and precipitation in these regions were major contributors to the high ET values. Decreased temperature and reduced vegetation cover area in the central and western sub-watersheds, compared with other sub-watersheds, resulted in a decrease in ET.

Fig. 6 shows that ET in the 1995-2010 period was not significantly different than that in the 1975-1994 period. This indicates the importance of the temperature increase in contrast with decreases in precipitation and land cover. The highest ET occurred in sub-watersheds 1, 2, 8, 6 and 5 in the downstream and northern areas, while the lowest ET occurred in sub watersheds 11, 13, 16 and 17 in the centre and south portions of the basin.

4.2.4.3. Spatial distribution of soil water

Similar to runoff and ET, in the northern, downstream and north-western sub-watersheds, soil moisture was higher in the 1975-1994 period than in the 1995-2010 period (Fig. 6). Land cover including forest and rangeland and high precipitation values were the most important reasons for high soil moisture values in these sub-watersheds. Soil moisture was considerably reduced due to decreased precipitation, land cover and increased barren and urban lands during the 1995-2010 period. Generally, flow component changes between the two periods showed that the role of climate variability outstripped that of land use change in decreasing runoff, ground water, soil moisture and ET.

4.3. Seasonal stream flow trends and sudden change point

The results of both sequential MK and Pettitt tests also indicated a sudden change in seasonal stream flow in 1994 ($p \leq 0.05$) (Fig. 7 and Table 12**),** a result consistent with the change point detected in annual stream flow. Thus, the study period (1975-2010) was also divided into reference (1975-1994) and change (1995-2010) periods for seasonal stream flow.

Figure 7:

Table 12:

The changes in runoff and precipitation for wet and dry seasons between the reference and change periods (Table 13) show that the decline in stream flow was considerable in both wet (34.37%) and dry (71.15%) seasons. Precipitation in the wet and dry seasons decreased by 15.27% and 6.66%, respectively.

Table 13:

4.4. Impacts of climate variability and human activity on seasonal stream flow

A straight-line plot of cumulative values of seasonal stream flow and precipitation from 1975 to 1994 (Fig. 8), shows the observed lines of cumulative runoff in both wet and dry seasons diverge from the predicted line in 1995, indicating that thereafter observed stream flow values were less than those predicted. These differences between cumulative values of observed and predicted runoff were likely related to the impacts of human activities. The results indicated that the stream flow changes affected by human activities in the wet and dry seasons were -23.38 mm (contribution of 42.5%) and -28.54 mm (contribution of 77.13%), respectively.

Total stream flow changes between reference and change periods for the wet and dry seasons were -55 mm and -37 mm, respectively (Table 14). These changes were influenced by the climatic variability to the extent of -31.62 mm (contribution of 57.5%) in the wet season and -8.46 mm (contribution of 22.87%) in the dry season. Importantly, in the dry season, stream flow changes influenced by anthropogenic activities may be considerably more important than those attributable to climatic variability. In a related study by Pirnia et al. (2014) in the Tajan River basin (near the Haraz basin and with similar climatic characteristics), increasing water transfer from river to riverside croplands was found to be the main reason for stream flow changes during the dry season.

Figure 8:

Table 14:

4.5. Attribution of human activities and climatic variability

Based on the land use maps of 1988, 2000 and 2013 (Table 6), the largest land use remained grassland despite a decreasing trend. Farmland and forest areas increased and decreased by 1.5% and 4%, respectively. Barren lands showed the most change among land use types with an increase of 6.5% (Table 6). Although, a decrease of forest and rangeland and an increase of barren lands could potentially lead to increases in stream flow, the offsetting effects of climate and human drivers led to a decrease of 43.4% in annual stream flow. In contrast, some human activities including the construction of regulative reservoirs could contribute considerably to decreases in stream flow. Although stream flow changes were influenced by a combination of climate and human factors, the present study shows that changes were generally influenced more by the latter. The effect of human activities on seasonal stream flow changes in the dry season was greater than in the wet season. In other words, during seasons when agriculture was carried out, land use changes due to increasing croplands seemed to have had a larger effect than other drivers.

Of great interest to researchers (*e.g*., Yuan et al., 2015), climatic variability generally would alter stream flow through a variation in meteorological variables; especially precipitation or ET_{pot} (Green et al., 2013; Tan and Gan, 2015). Hydrological changes resulting from climate variability may affect the performance and biodiversity of river ecosystems (Pall et al., 2011). The results of the present study indicate that climate variability contributed more than human activities to stream flow changes during the wet season. ET_{pot} effects on stream flow changes were negligible since there was little difference between reference and change periods. Thus, among meteorological variables, precipitation made a more important contribution to stream flow changes of the Haraz

River basin than did ET_{pot}. Changes in precipitation were considerable in the wet season, when the stream flow changes were influenced more by climate variability.

Similar results were obtained for the hydrological sensitivity method and hydrological modelling (SWAT) when separating climate variability and human activity effects on annual stream flow. However, we believe the results of the SWAT model to be more useful given the numerous parameters it employs: climate variables (precipitation, temperature, relative humidity, wind speed, radiation) and terrestrial variables (land use, soil, DEM, slope). In contrast, the hydrological sensitivity and double mass curve methods consider only climate variables, especially precipitation. Because human impact is a gradual and continuous process and changes over time, consideration of water resource components, especially stream flow, by the SWAT model in the periods before and after the sudden change may better reveal the effects of human activities. Comparatively, the hydrological sensitivity method does not consider the impacts of human activities as a gradual and continuous process.

In this study, we carried out stream flow trend analysis and evaluated the separate of the impacts of human and climate factors to stream flow changes; however, we did not consider the effects of reservoir construction as a factor effecting stream flow (Zhang et al., 2011; Wang et al., 2016). Future studies should consider the contribution of this factor on stream flow alterations.

5. Conclusions

The aim of the present study was to analyse the impacts of climatic and human factors on water resource components, especially stream flow, for the Haraz River basin between 1975 and 2010. For this purpose, temporal trends of annual and seasonal stream flow along with separation of climate variability and human activities effects were analysed, and the following major conclusions were reached:

(*i*) MK test results showed sudden change points in both annual and seasonal stream flows in 1994, along with a significant ($p \leq 0.05$) decreasing trend. Accordingly, the stream flow record (1975-2010) was divided into reference (1975-1994) and change (1995-2010) periods.

(*ii*) The hydrological process was mainly influenced by climatic variability and human activities which annual stream flow changes were driven more by human activities than shifts in climate. Based on both the hydrological sensitivity method and the SWAT model, human activities contributed 70.15% and 65.22%, respectively, to changes in annual stream flows, while climate variability contributed the remaining 29.85% and 34.78%.

(*iii*) To develop greater confidence and less uncertainty in the results, individual impacts of land use changes were considered as being among the most important human activities. We also evaluated the effects of climatic variability on stream flow and other water resource components including ET, soil moisture and ground water. The effect of shifting climate was considerably greater than that of changing land use. Other human activities such as regulative reservoirs can have significant impacts on water resources components, especially changes in stream flow.

(*iv*) Changes to the spatial distribution of water resources components (soil water, stream flow and ET) showed that climate (increased temperature and decreased precipitation) had considerably more effect than land use changes, particularly to stream flow. The changes in water resource components in sub-watersheds 1, 2, 8, 10 and 12 with greater density of forest lands revealed the more important contribution of climate compared to land use change. Stream flow in these sub watersheds decreased as a result of lower precipitation and higher temperatures, despite a decrease in forested lands and an increase in barren and urban lands. Thus, climate variability effects dominated over those brought on by land use changes. Negligible changes in ET, especially in sub watersheds 1, 2, 8 and 10 with high forest cover showed the offsetting effects of temperature increases (ET increase) and decreases in precipitation and land cover (ET decrease).

(*v*) The variability of climatic factors and human activities contributed 57.5% and 42.5% to seasonal runoff changes in the wet season, respectively, and 22.87% and 77.13% in the dry season. Stream flow in the dry season was evidently mainly affected by human activities.

The results of this study can better inform water resources management practices throughout the basin and also at the sub-watershed scale. Investigation of climate variability and land use change effects on stream flow by the SWAT model in dry and wet seasons could reveal seasonal effects of land use change, especially under constant climatic conditions and individual land use. Many studies have assessed the combined and separated impacts of human activities and climate change on stream flow in large rivers. The contribution of storage and regulative dams as a part of human activities, however, also has an important role on the magnitude, frequency and duration of flows on the river downstream. This could be considered separately from other human activities (such land use change) and should be investigated in future studies.

Acknowledgements

The authors are grateful to the Islamic Republic of Iran Meteorological Organization (IRIMO) and the Water Resources Management Company of the Ministry of Energy, Islamic Republic of Iran for the provision of meteorological and hydrological data.

References

Abbaspour, K. C., 2007. SWAT-CUP Calibration and Uncertainty Programs for SWAT. Modsim International Congress on Modelling & Simulation Land Water & Environmental Management Integrated Systems for Sustainability, 364(3): 1603-1609.

Abbaspour, K. C., 2008. SWAT-CUP2: SWAT calibration and uncertainty programs; user manual, Dept. of Systems Analysis, Integrated Assessment and Modelling SIAM, Eawag, Swiss Federal Institute of Aquatic Science and Technology, Duebendorf, Switzerland.

Abbaspour, K.C., 2011. SWAT-CUP4: SWAT Calibration and Uncertainty Programs - A user Manual. Eawag: Swiss Federal Institute of Aquatic Science and Technology.

Abbaspour, K.C., Rouholahnejad, E., Vaghefi, S., Srinivasan, R., Yang, H., Kløve, B., 2015. A continental-scale hydrology and water quality model for Europe: Calibration and uncertainty of a high-resolution large-scale SWAT model. Journal of Hydrology, 524: 733-752.

Ahn, K.H. and Merwade, V., 2014. Quantifying the relative impact of climate and human activities on streamflow. Journal of hydrology, 515, pp.257-266.

Ahn, K.H. and Merwade, V., 2017. The effect of land cover change on duration and severity of high and low flows. Hydrological Processes, 31 (1), pp. 133-149.

Ahn, K.H. and Palmer, R.N., 2015. Trend and variability in observed hydrological extremes in the United States. Journal of Hydrologic Engineering, 21(2), p.04015061.

Ahn, K.H., Merwade, V., Ojha, C.S.P., Palmer, R.N., 2016. Quantifying relative uncertainties in the detection and attribution of human-induced climate change on winter stream flow. Journal of Hydrology, 542, pp.304-316.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M., 1998. Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56. FAO, Rome, 300(9), p.D05109.

Arab Ameri, A., Pourghasemi, H., Shirani, K. 2017. Flood susceptibility zonation using new ensemble Bayesian-AHP methods (Case study: Neka Watershed, Mazandaran Province), Iranian journal of Ecohydrology, 4 (2), 447-462.

Ashraf, F. B., Haghighi, A. T., Marttila, H. and Kløve, B. 2016. Assessing impacts of climate change and river regulation on flow regimes in cold climate: a study of a pristine and a regulated river in the sub-arctic setting of Northern Europe. Journal of Hydrology, 542, 410-422.

Ashraf, F. B., Haghighi, A. T., Riml, J., Alfredsen, K., Koskela, J. J., Kløve, B., and Marttila, H. 2018. Changes in short term river flow regulation and hydropeaking in Nordic rivers. Scientific reports, 8(1), 17232.

Bao Z, Zhang J, Wang G, et al. 2012. Attribution for decreasing stream flow of the Haihe River basin, northern China: Climate variability or human activities? Journal of Hydrology. 460-461, 117-129.

Budyko, M.I. 1948. Evaporation under Natural Conditions; Gidrometeorizdat: Leningrad, Russia.

Budyko, M.I. 1974. Climate and Life, 508 pp., Academic, New York.

Chen, Z., Chen, Y. and Li, B., 2013. Quantifying the effects of climate variability and human activities on runoff for Kaidu River Basin in arid region of northwest China. Theoretical and applied climatology, 111(3-4), pp.537-545.

Cheng, Y., He, H., Cheng, N. and He, W., 2016. The effects of climate and anthropogenic activity on hydrologic features in Yanhe River. Advances in Meteorology, Article ID 5297158, 11 pages.

Dai, A., 2013. Increasing drought under global warming in observations and models. Nature Climate Change, 3(1), pp.52-58.

Darabi, H., Choubin, B., Rahmati, O., Haghighi, A. T., Pradhan, B., and Kløve, B. 2019. Urban flood risk mapping using the GARP and QUEST models: A comparative study of machine learning techniques. Journal of Hydrology, 569, 142-154.

Darabi, H., Shahedi, K., Solaimani, K., Miryaghoubzadeh, M. 2014. Prioritization of subwatersheds based on flooding conditions using hydrological model, multivariate analysis and remote sensing technique. Water and environment journal, 28(3), 382-392.

Fazel, N., Haghighi, A. T., and Kløve, B. 2017. Analysis of land use and climate change impacts by comparing river flow records for headwaters and lowland reaches. Global and Planetary Change, 158, 47-56.

Gao, J.H., Jia, J., Kettner, A.J., et al., 2014. Changes in water and sediment exchange between the Changjiang River and Poyang Lake under natural and anthropogenic conditions, China. Science of the total environment, 481, pp.542-553.

Gao, P., Geissen, V., Ritsema, C.J., Mu, X.M. and 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 Discussions, 17, pp.961-972.

Ghanghermeh, A., Roshan, G. 2015. Application of TOPSIS Index in Monitoring of Droughts and Wet for Golestan providence, Journal of the Earth and Space Physics, 41(3), pp. 547-563.

Ghasemi, A., Moogooei, M., 2017. The investigation of stream f low changes in Chaharmahal-Bakhtiari Rivers, Scientific- Research Quarterly of Geographical Data (SEPEHR), 26 (102), 163-173. (in Persian).

Green, A.W., Hooten, M.B., Grant, E.H.C. and Bailey, L.L., 2013. Evaluating breeding and metamorph occupancy and vernal pool management effects for wood frogs using a hierarchical model. Journal of Applied Ecology, 50(5), pp.1116-1123.

Haghighi, A. T., and Kløve, B. 2013. Development of a general river regime index (RRI) for intra-annual flow variation based on the unit river concept and flow variation end-points. Journal of hydrology, 503, 169-177.

Haghighi, A. T., and Kløve, B. 2017. Design of environmental flow regimes to maintain lakes and wetlands in regions with high seasonal irrigation demand. Ecological engineering, 100, 120-129.

Haghighi, A. T., Menberu, M. W., Aminnezhad, M., Marttila, H., and Kløve, B. 2016. Can lake sensitivity to desiccation be predicted from lake geometry?. Journal of Hydrology, 539, 599-610.

Huang, S., Chang, J., Huang, Q. and Chen, Y., 2014. Spatio-temporal changes and frequency analysis of drought in the Wei River Basin, China. Water resources management, 28(10), pp.3095-3110.

IPCC, 2013. In: Stocker, T.F., Qin, D.H., Plattner, G.K., Tignor, M., Allen, S.K., Boschung, J., Nauels, A., Xia, Y., Bex, V., Midgley, P.M. (Eds.), Climate Change 2013: The Physical

Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 1535. http://dx.doi.org/10.1017/CBO9781107415324.

Khoshravesh, M., Abedi-Koupai, J., Nikzad-Tehrani, E. 2016. Detection of Trends in Hydro-Climatological Variables Using Parametric and Non-Parametric Tests in Neka Basin. JWSS, ; 19 (74), 1-14. (in Persian)

Lee, S. and Kim, S. U. 2017. Quantification of Hydrological Responses Due to Climate Change and Human Activities over Various Time Scales in South Korea. Water, 9(1), 1-21.

Li, B., Chen, Y., Chen, Z. and Li, W., 2012. Trends in runoff versus climate change in typical rivers in the arid region of northwest China. Quaternary International, 282, pp.87-95.

Li, L.J., Zhang, L., Wang, H., Wang, J., Yang, J.W., Jiang, D.J., Li, J.Y. and Qin, D.Y., 2007. Assessing the impact of climate variability and human activities on streamflow from the Wuding River basin in China. Hydrol. Process. 21, 3485-3491.

Menberu, M. W., Haghighi, A. T., Ronkanen, A. K., Kværner, J., and Kløve, B. 2014. Runoff curve numbers for peat-dominated watersheds. Journal of Hydrologic Engineering, 20(4), 04014058.

Mirakhorlou, KH. and Akhavan, R. 2016. Evaluation of Changes in Hirkani forests from 2004 to 2016. Iran's Nature, 2 (3), 40-45. (in Persian)

Mousavi, R., Marof, S., 2017. Investigation of the hydrologic response of river flow to climate change (Case study: Dez Dam Basin), Journal of Water and Soil Conservation, 23 (6), 333-348. (in Persian).

Namdar, M., Kavian, A. and Bahri, M., 2013. Surface Runoff Prediction based on Climate Change in the Haraz basin, MSc Thesis, Sari University of Agricultural Sciences and Natural Resources, (in Persian)

Neitsch, S.L., Arnold, J.G., Kinir, J.R. and Wiliams, J.R., 2011. Soil and Water Assessment Tool: Theoretical Documentation 2009. Technical report no. 406 edn. Texas Water Resources Institute-Texas A&M University, College Station.

Pall, P., Aina, T., Stone, D.A., Stott, P.A., Nozawa, T., Hilberts, A.G., Lohmann, D. and Allen, M.R., 2011. Anthropogenic greenhouse gas contribution to flood risk in England and Wales in autumn 2000. Nature, 470(7334), pp.382-385.

Peng, D., Qiu, L., Fang, J. and Zhang, Z., 2016. Quantification of climate changes and human activities that impact runoff in the Taihu Lake basin, China. Mathematical Problems in Engineering, Article ID 2194196, 7 pages.

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

Pirnia, A., Golshan, M., Darabi, H., Adamowski, J., Rozbeh, S. 2018. Using the Mann–Kendall test and double mass curve method to explore stream flow changes in response to climate and human activities. Journal of Water and Climate Change.https://doi.org/10.2166/wcc.2018.162

Pirnia, A., Habibnezhad, M. and Solaimani, K., 2014. Investigation of climate change effect on runoff in Tajan River Basin, Mazandaran province. Journal of Watershed Management Researches, 102, 1-11 (in Persian)

Qin, D., Plattner, G.K. and Tignor, M., 2014. Climate Change 2013: The Physical Science Basis. Cambridge University Press, Cambridge, UK.

Rahimi, D. 2016. Resources in the Impacts Climate Change on Floods in North of Iran. Geography and Environmental planning, 27 (1), 89-102. (in Persian)

Rousta, I., Doostkamian, M., Taherian, A.M., Haghighi, E., Ghafarian Malamiri, H.R. and Ólafsson, H., 2017. Investigation of the Spatio-Temporal Variations in Atmosphere Thickness Pattern of Iran and the Middle East with Special Focus on Precipitation in Iran. Climate, 5 (4), p.82

Sadegh, M., Majd, M. S., Hernandez, J., and Haghighi, A. T. 2018. The quest for hydrological signatures: Effects of data transformation on Bayesian inference of watershed models. Water resources management, 32(5), 1867-1881.

Searcy, J.K. and Hardison, C.H., 1960. Double-mass curves.

Shrestha, N.K., Du, X. and Wang, J. 2017. Assessing climate change impacts on fresh water resources of the Athabasca River Basin, Canada. Science of the Total Environment, 601-602, pp.425-440.

Song, C., Huang, B., Ke, L. and Richards, K.S., 2014. Seasonal and abrupt changes in the water level of closed lakes on the Tibetan Plateau and implications for climate impacts. Journal of Hydrology, 514, pp.131-144.

Song, W. Z., Jiang, Y. Z., Lei, X. H., Wang, H and Shu, D. C. 2015. Annual runoff and flood regime trend analysis and the relation with reservoirs in the Sanchahe River Basin, China; Quatern. Int. 380-381 197-206.

Sun, G., McNulty, S.G., Lu, J., Amatya, D.M., Liang, Y. and Kolka, R.K., 2005. Regional annual water yield from forest lands and its response to potential deforestation across the southeastern United States. Journal of Hydrology, 308(1), pp.258-268.

Sun, G., Zhou, G., Zhang, Z., Wei, X., McNulty, S.G. and Vose, J.M., 2006. Potential water yield reduction due to forestation across China. Journal of Hydrology, 328(3), pp.548-558.

Tan, X. and Gan, T.Y., 2015. Contribution of human and climate change impacts to changes in stream flow of Canada. Scientific reports, 5.

Tian, P., Mu, X., Liu, J., Hu, J. and Gu, C., 2016. Impacts of climate variability and human activities on the changes of runoff and sediment load in a catchment of the Loess Plateau, China. Advances in Meteorology, Article ID 4724067, 15 pages.

Torabi Haghighi, A., Menberu, M. W., Darabi, H., Akanegbu, J., Kløve, B. 2018. Use of remote sensing to analyse peatland changes after drainage for peat extraction. Land degradation & development, 29(10), 3479-3488.

Wang, H., Chen, L. and Yu, X., 2016. Distinguishing human and climate influences on stream flow changes in Luan River basin in China. Catena, 136, pp.182-188.

Wu, Y., Liu, S., Sohl, T.L. and Young, C.J., 2013. Projecting the land cover change and its environmental impacts in the Cedar River Basin in the Midwestern United States. Environmental Research Letters, 8(2), p.024025.

Xu, C., Li, J., Zhao, J., Gao, S. and Chen, Y. 2015. Climate variations in northern Xinjiang of China over the past 50 years under global warming; Quatern. Int. 358 83-92.

Yan, R., Zhang, X., Yan, S., Zhang, J. and Chen, H., 2017. Spatial patterns of hydrological responses to land use/cover change in a catchment on the loess plateau, China. Ecological Indicators.

Yuan, Y., Zeng, G., Liang, J., et al., 2015. Variation of water level in Dongting Lake over a 50-year period: Implications for the impacts of anthropogenic and climatic factors. Journal of Hydrology, 525, pp.450-456.

Zargoosh, Z., Kavian, A., Darabi, H., and Jafarian, Z., 2014. Prediction of landuse change by using Statistical methods in Haraz River Basin. MSc Thesis, Sari University of Agricultural Sciences and Natural Resources, (in Persian)

Zhang, A., Zhang, C., Fu, G., Wang, B., Bao, Z. and Zheng, H., 2012. Assessments of impacts of climate change and human activities on runoff with SWAT for the Huifa River Basin, Northeast China. Water resources management, 26 (8), pp.2199-2217.

Zhang, C., Zhang, B., Li, W. and Liu, M., 2014. Response of stream flow to climate change and human activity in Xitiaoxi river basin in China. Hydrological Processes, 28(1), pp.43-50.

Zhang, D., Liu, X., Zhang, Q., Liang, K. and Liu, C., 2016. Investigation of factors affecting intra-annual variability of evapotranspiration and stream flow under different climate conditions. Journal of Hydrology, 543, pp.759-769.

Zhang, L., Karthikeyan, R., Bai, Z. and Srinivasan, R., 2017. Analysis of stream flow responses to climate variability and landuse change in the Loess Plateau region of China. Catena, 154, pp.1-11.

Zhang, Q., Gu, X., Singh, V.P., Xu, C.Y., Kong, D., Xiao, M. and Chen, X., 2015. Homogenization of precipitation and flow regimes across China: Changing properties, causes and implications. Journal of Hydrology, 530, pp.462-475.

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

Zhang, Y., You, Q., Chen, C. and Ge, J., 2016. Impacts of climate change on stream flows under RCP scenarios: A case study in Xin River Basin, China. Atmospheric Research, 178, pp.521-534.

Zhao, J., Huang, Q., Chang, J., Liu, D., Huang, S. and Shi, X., 2015. Analysis of temporal and spatial trends of hydro-climatic variables in the Wei River Basin. Environmental research, 139, pp.55-64.

Figures:

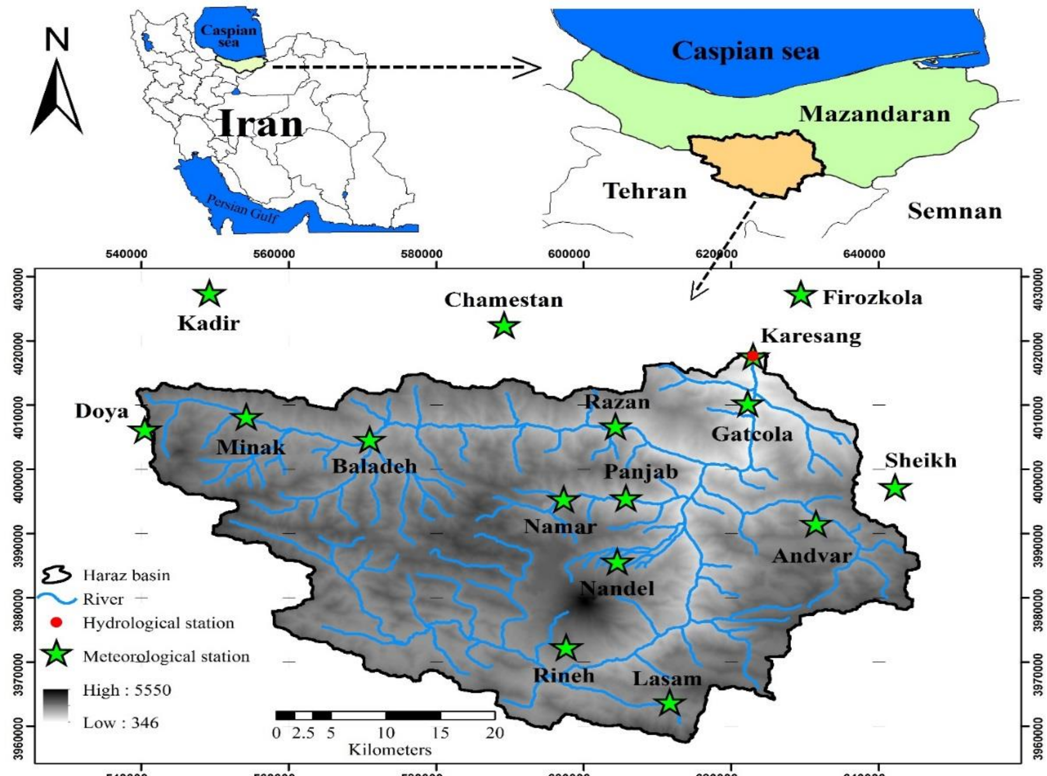

Fig. 1. Location of the Haraz River basin in Mazandaran province, northern Iran

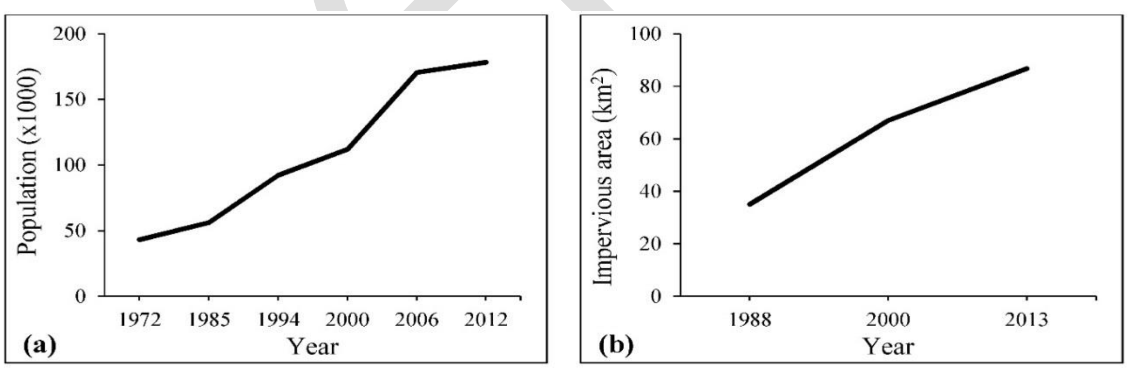

Fig. 2. Population growth and impervious area in the Haraz basin. a) Population growth; b) Impervious area.

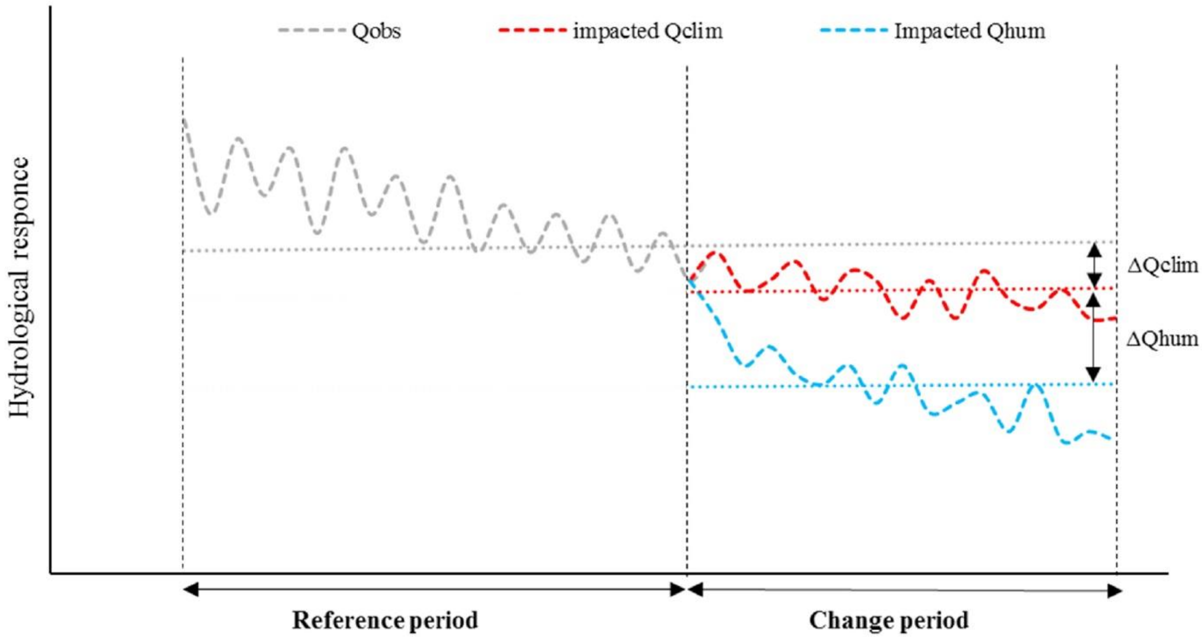

Fig. 3. Schematic diagram to separate impacts of climate and human factors on stream flow changes.

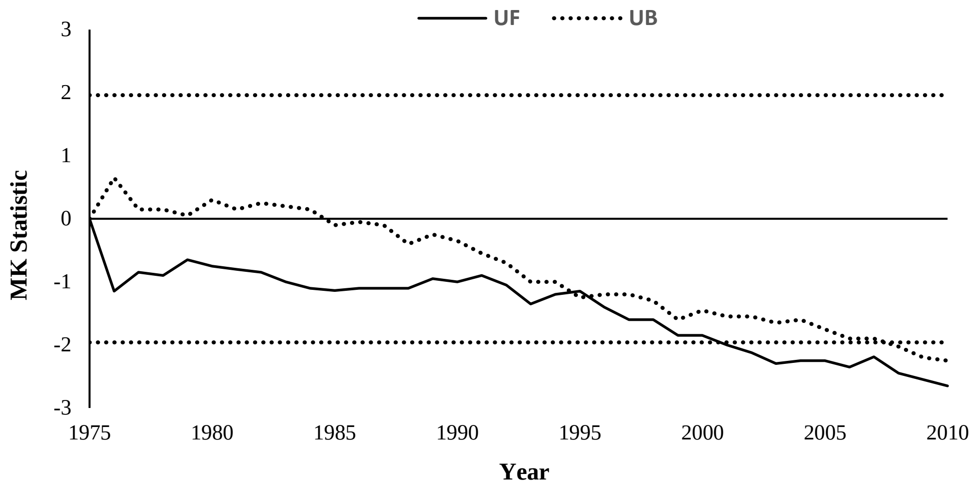

Fig. 4. MK sudden change point detection in time series of annual stream flow

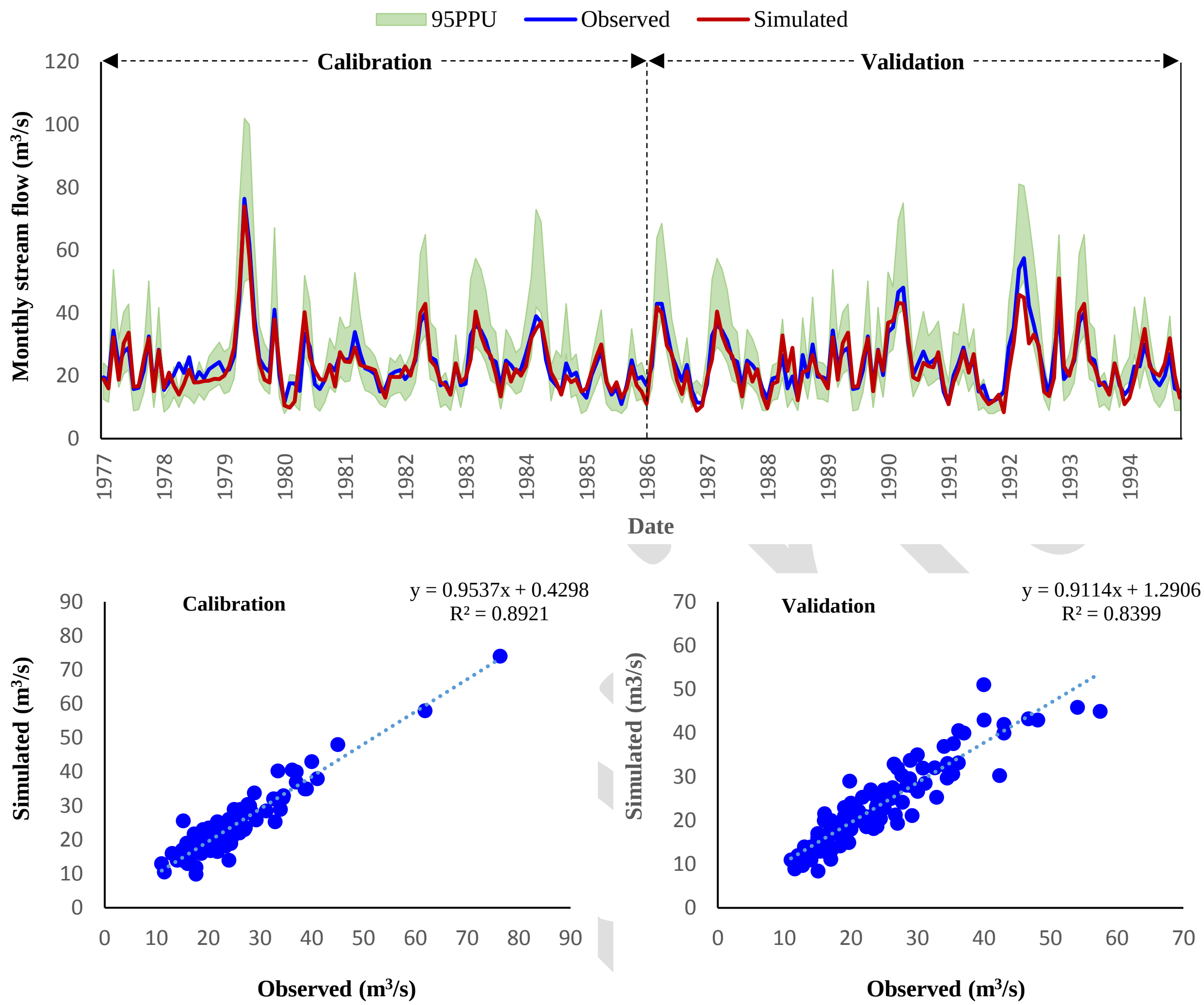

Fig. 5. Comparison of observed and simulated stream flow at a monthly timescale during the periods of calibration (1977-1985) and validation (1986-1994)

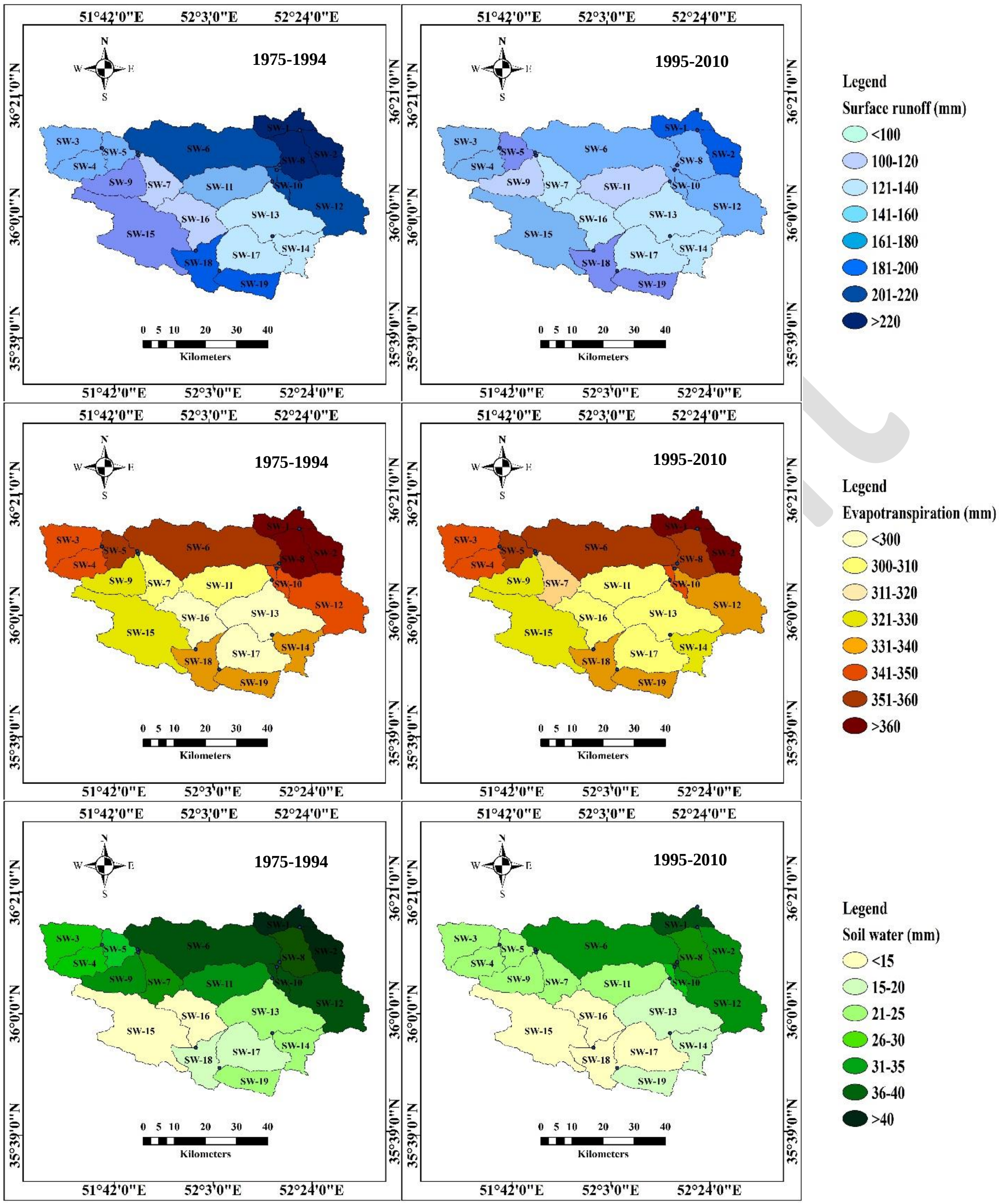

Fig. 6. Changes in stream flow, evapotranspiration and soil water (soil moisture) between the reference (1975-1994) and change (1995-2010) periods.

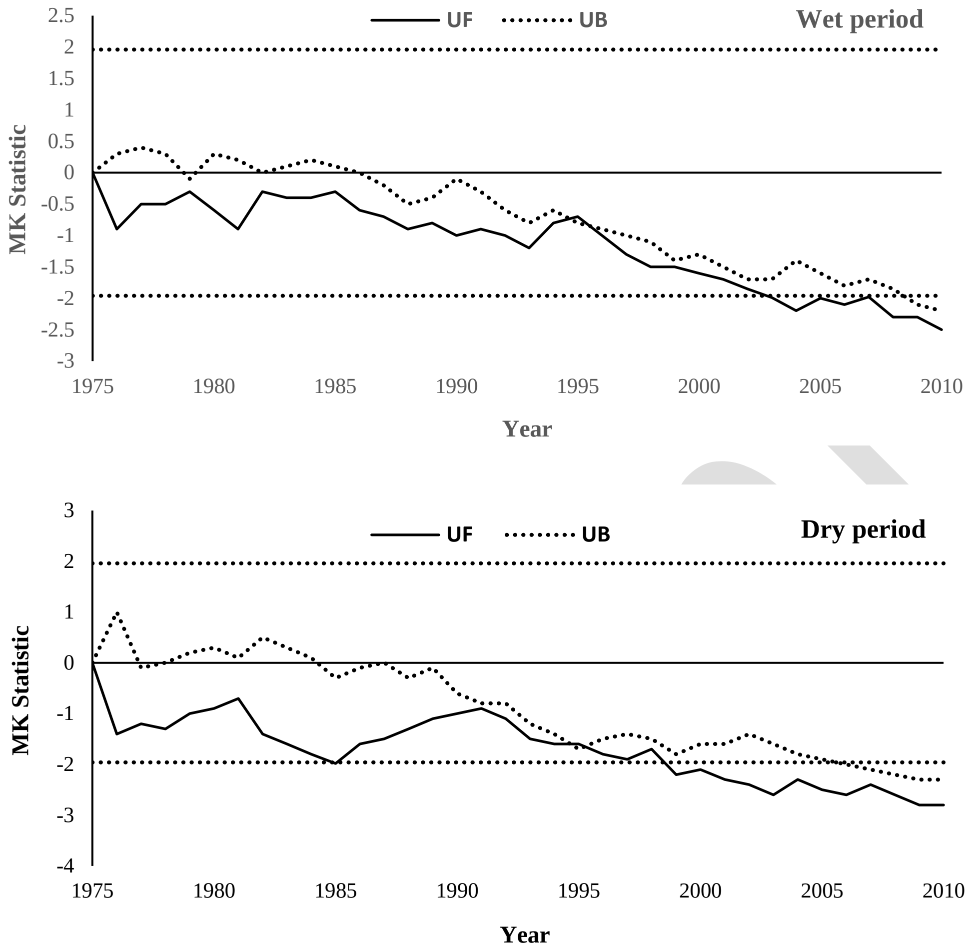

Fig. 7. Seasonal stream flow and MK sudden change point

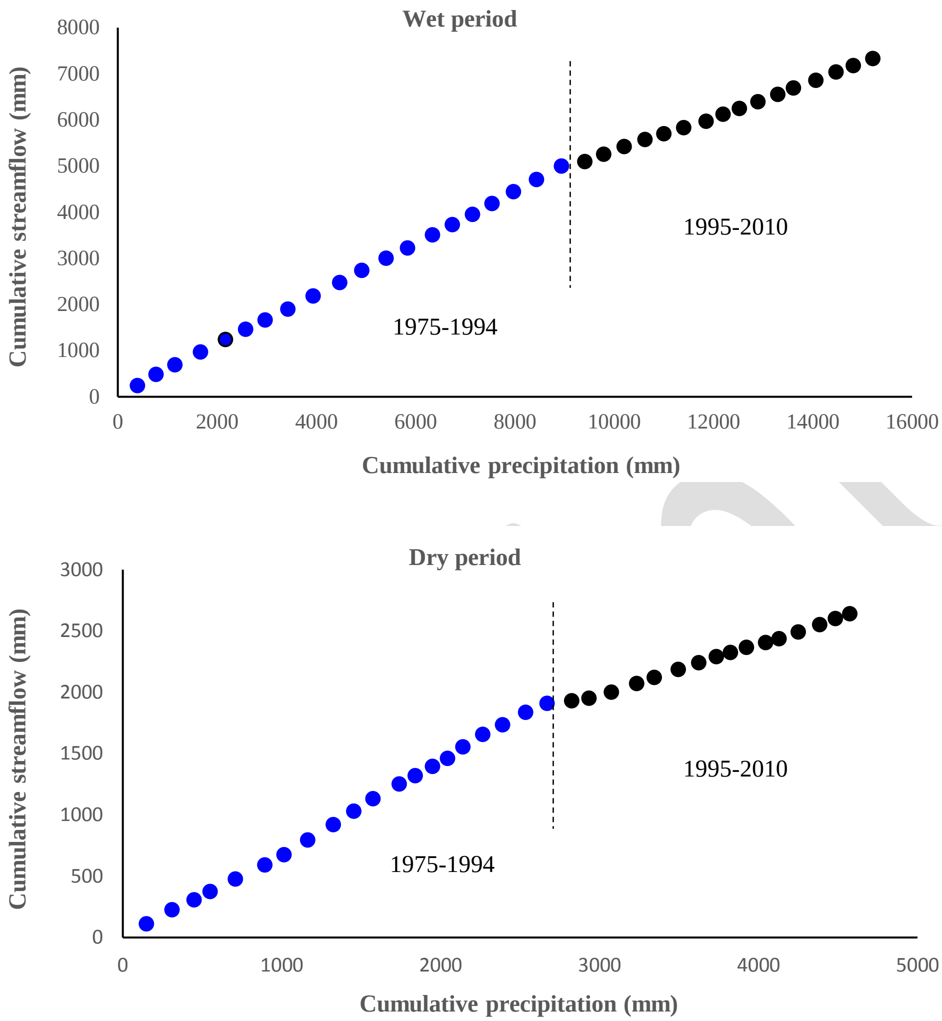

Fig. 8. Double mass curve for seasonal stream flow and precipitation

Tables:

Table 1 Data sources

Data	Parameters	Time	Source
Climatic data	Precipitation, Temperature, Humidity, Sunshine	1975-2010	Islamic Republic of Iran Meteorological Organization (IRIMO)
Land use	Land use from satellite data	1988, 2000, 2013	United States Geological Survey (USGS)
Elevation (DEM)	ASTER DEM	-	USGS
Soil	Soil	-	Food and Agriculture Organization of the United Nations (FAO)
Hydrometric data	Stream flow data	1975-2010	Ministry of Energy, Islamic Republic of Iran

Table 2 Equations for annual actual evapotranspiration

Name of function	Function
Schreiber (1904)	$F(\emptyset) = 1 - e^{-\emptyset}$
Ol'dekop (1911)	$F(\emptyset) = \emptyset \tanh(1/\emptyset)$
Budyko (1948)	$F(\emptyset) = \left[\emptyset \tanh(1/\emptyset)(1 - e^{-\emptyset})\right]^{1/2}$
Pike (1964); Turc (1954)	$F(\emptyset) = 1/\sqrt{1 + \emptyset^{-2}}$
Fu et al. (2007)	$F(\emptyset) = 1 + \emptyset - (1 + \emptyset^{\alpha})^{1/\alpha}$
Zhang et al. (2001)	$F(\emptyset) = (1 + \omega\emptyset)/(1 + \omega\emptyset + 1/\emptyset)$

Table 3 Statistical trend analysis results

Data	Record length	MK statistic
Wet period	1975-2010	-2.50
Dry period	1975-2010	-2.18
Annual	1975-2010	-3.67

Table 4 Results of the Pettitt and MK tests under the 5% significance level

Data	Pettitt test		MK	
	p-value	Change point	p-value	Change point
Annual	0.0001	1994	0.0007	1994

Table 5 Annual precipitation (P), temperature (T), potential evapotranspiration (ET_{pot}) and stream flow (Q) changes between the two periods

Period	P (mm)	T (°C)	ET_{pot} (mm)	Q (mm)
1975-1994	613	12.5	1252	212
1995-2010	531	13.1	1263	120
Change	-82 (13.37%)	0.6 (4.8%)	11 (0.878%)	-92 (43.4%)

Table 6 The proportion of total land area (%) under various land uses in different years

Land use	1988	2000	2013	Average
Grassland	80.95	80.29	75.857	79.032
Forest	10.284	8.752	6.084	8.373
Farmland	5.287	6.461	6.851	6.2
Barren land	2.33	4.55	8.957	5.279
Construction land	0.874	1.669	2.161	1.568
Water	0.275	0.108	0.09	0.157

Table 7 Climate and human factors impacts on annual stream flow

	ΔQ	ΔQ^{clim}	ΔQ^{hum}
Quantity/mm	-92	-29.63	-62.37
Contribution rate (%)	100%	32.2%	67.8%

Table 8 Sensitivity analysis of SWAT model parameters.

Rank	Name	Description	t-value	p-value
1	r_CN2.mgt	SCS runoff curve number for moisture condition II	17.6	0.00
2	v_ALPHA_BNK.rte	Base flow alpha factor for bank storage	8.4	0.00
3	v_CH_K2.rte	Effective hydraulic conductivity (mm/h)	3.9	0.007
4	r_SOL_BD().sol	Soil bulk density	3.2	0.009
5	v_SMTMP.bsn	Snow melt base temperature (◦C)	2.7	0.01
6	v_SMFMX.bsn	Melt factor for snow on June 21 (mm water/◦C-day)	2.6	0.01
7	v_ALPHA_BF.gw	Base flow alpha factor	2.35	0.02
8	v_GW_DELAY.gw	Groundwater delay time (days)	2.17	0.03
9	v_SURLAG.bsn	Surface runoff lag time (days)	2	0.04
10	v_SFTMP.bsn	Snowfall temperature (◦C)	1.92	0.057
11	v_CANMX.hru	Maximum canopy storage (mm)	1.79	0.063

Table 9 SWAT model performance in calibration and validation periods

Period	P-factor	R-factor	NSE	R^2
Calibration (1977-1985)	0.78	0.96	0.79	0.89
Validation (1986-1994)	0.85	0.82	0.77	0.84

Table 10 Human activities and climate variability impacts on the annual stream flow decrease (mm)

Period	Observed	Simulated	Total runoff changes	Contribution of climate variability	Contribution of human activities
1975-1994	212	188			
1995-2010	120	156	-92	-32 (34.78%)	-60 (65.22%)

Table 11 Changes in water resources components (mm) caused by climate variability and land use change

Period	Precipitation	ET	Stream flow	Ground water	Soil water
Land use change					
1975-1994	568	321	182	37	28
1995-2010	568	318	188	36	26
Change		-3 (0.93%)	6 (3.29%)	-1 (2.7%)	-2 (7.14%)
Climate variability					
1975-1994	613	328	205	46	34
1995-2010	531	315	147	39	30
Change	-82 (13.37%)	-13 (3.96%)	-58 (28.29%)	-7 (15.2%)	-4 (11.76%)

Table 12 Results of change point detection by the Pettitt and MK tests under the 5% significance level

Data	Pettitt test		MK	
	p-value	Change point	p-value	Change point
Dry season	0.0023	1994	0.008	1994
Wet season	0.0004	1994	0.003	1994

Table 13 Seasonal precipitation and stream flow changes between the reference and change periods

Period	Precipitation		Stream flow	
	Wet season (mm)	Dry season (mm)	Wet season (Q_w) (mm)	Dry season (Q_d) (mm)
1975-1994	478	135	260	102
1995-2010	405	126	205	65
Change	-73 (15.27%)	-9 (6.66%)	-55 (21.15%)	-37 (36.27%)

Table 14 Impacts of climate variability and human activities on seasonal stream flow

		ΔQ	ΔQ^{clim}	ΔQ^{hum}
Wet season	Quantity/mm	-55	-31.62	-23.38
	Contribution rate (%)	100%	57.5%	42.5%
Dry season	Quantity/mm	-37	-8.46	28.54
	Contribution rate (%)	100%	22.87%	77.13%