Hydrological time series analysis and modelling using statistical tests and linear time series models (case study: West Azerbaijan province of Iran)

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Abstract: In this paper, the time series of hydrological processes analysed using ADF, KPSS, Mann-Kendall tests and linear time series models on monthly scale in the West Azerbaijan province of Iran. Significant decreasing trend in precipitation and stream flow discharge were observed. Also, non-stationarity in precipitation was observed in four studied basins. Decreasing stream flow discharge partially can be a result of trends in precipitation and evaporation. The population growth, land use changes and increase in water withdrawal are other reasons to blame. The results of linear time series modelling indicates that ARMA models for modelling stream flow only appears when precipitation or evaporation models have a MA component. On the other hand, when precipitation and evaporation models only have AR component, stream flow models are also follow autoregressive models and moving average components vanish. Moreover, in climatically homogenous basins, the same models were best-fitted for different hydrologic processes.

Keywords: precipitation; evaporation, stream flow; trend; stationarity; augmented Dickey-Fuller; ADF; Kwiatkowski-Phillips-Schmidt-Shin; KPSS; Mann-Kendall; Iran.

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1 Introduction

Grafting rapid growth of population, economy and significant changes in lifestyle which has been brought the growing need of water, onto limited water resources has been lead to water scarcity in many part of the world especially developing country like Iran. To plan and management those endangered water resources in order to take into account sustainable development, recognition, determination and modelling all of the related processes in temporal and spatial scales are required. One of the main governing phenomenon in water resources in a catchment is water cycle in which evaporation, precipitation and stream flow are the main components. Evaporation, precipitation and stream flow time series have important information about climate variability, climate change, seasonal fluctuation and stationarity. Therefore, analyse and modelling hydrological time series are vital to sustainable development. Hydrologic time series modelling have been widely used in some planning and management of water resources systems issues. determining storage volume of reservoir, evaluating the reservoir reliability, assessing the performance of specific strategy for water resources management under various potential hydrological scenarios, evaluating the efficiency of pressurised irrigation systems in conditions of system inputs uncertainty (Salas et al., 1980; Loucks et al., 1981), drought and flood analysis (Nazeri and Khalili, 2014; Hosseini-Moghari and Araghinejad, 2015), stream flow forecasting (Amiri, 2015) and many other relevant issues. Time series analysis is a powerful tool to reveal the governing phenomenon underlying hydrological time series. Trend, stationarity and nonlinearity can be detected through time series analysis (Haddad and Moravej, 2015).

Trend detection researches are performed in all around the world for evaporation, precipitation and stream flow time series (Burn and Elnur, 2002; Novotny and Stefan, 2007; Modarres and Silva, 2007; Modarres and Sarhadi, 2009; Xu et al., 2010; Karpozos et al., 2010; Tabari and Talaee, 2011; Sonali and Kumar, 2012; Tabari and Talaee, 2013).

Many studies focused on stationarity of hydrological time series, mostly to investigate the impact of climate change in order to considerate sustainable development. Augmented Dickey-Fuller (ADF) and Kwiatkowski-Phillips-Schmidt-Shin (KPSS) test are most widely used among stationarity tests. ADF test employed to test stationarity of stream flow time series (Wang et al., 2006; Jarvis et al., 2013), precipitation (Jarvis et al., 2013; Abdul-Aziz et al., 2013; Wang et al., 2013), temperature (Jarvis et al., 2013) and precipitation extreme values (Yilmaz et al., 2014). KPSS test used to test stationarity of stream flow time series (Wang et al., 2006; Karthikeyan and Kumar, 2013; Jarvis et al., 2013), temperature (Jarvis et al., 2013), precipitation (Karthikeyan and Kumar, 2013; Jarvis et al., 2013), water temperature and dissolve oxygen (DO) (Arya and Zhang, 2014), ground water level (Graf, 2014), precipitation extreme values (Yilmaz et al., 2014). Useful information about generator process of time series can be extracted from results of stationarity tests. Jarvis et al. (2013) investigated the stationarity of precipitation, temperature and stream flow time series of Queensland, Australia with

ADF and KPSS test. The results show the stationarity of studied time series, so there is no evidence on climate change in studied area. Arya and Zhang (2014) studied the stationarity of water temperature and DO in four station of Stillaguamish River, Washington. They used ADF and KPSS test. Stationarity results show that water temperature and DO are stationary in one station, non-stationary in two stations and have long memory in one station.

Investigation on relationship between hydrological time series using time series models have been carried out. Miller (1979) pointed out the relationship between precipitation and stream flow discharge. In this research effect of precipitation on residual series of AR (4) model which fitted on daily stream flow discharge time series were investigated. Salas et al. (1980) achieved a relationship between water balance components and ARMA (1, 1) model in annual scale considering a river system, which includes precipitation, evaporation, runoff, groundwater recharge, stream flow discharge, and infiltration to the aquifer. This researcher showed that in a basin, general process of flow discharge follows ARMA (1, 1) model. This relation can be easily generalised to the monthly scale. The AR component, which presents the memory of stream flow, is caused by snow melting and groundwater recharge. The runoff coefficient (as a precipitation to runoff convertor) appeared in time step of t in MA component. A combination of complex factors such as precipitation coefficients, infiltration, evaporation, and recharge has appeared in the MA component with $t - 1$ time step. Wang et al. (2005a) mentioned the effect of precipitation on volatility of daily stream flow discharge time series. But, the effects of precipitation model were not investigated. Moravej et al. (2015) showed that there is a correlation between the trend of precipitation and stream flow discharge of western basins of Urmia Lake, also the relation of precipitation, evaporation and stream flow discharge time series models were reported. As they stated, with increase of weight of moving average component of precipitation the weight of moving average component of stream flow discharge model increases. In other word there is a significant straight relation between precipitation volatility and stream flow discharge volatility which appears in selected time series models.

Time series analysis and modelling of precipitation, evaporation and stream flow time series are most important controller of available water resources thus far have been carried out separately, and the majority of these studies have been conducted on the stream flow and precipitation processes; whereas, for acquiring a comprehensive vision of hydrological conditions in the basin scale, three mentioned processes should be analysed in parallel to each other. In addition to trend analysis, which is performed in other researchers, stationarity and best-fitted models play an important role in which they must be taken into consideration. The main objectives of this study are

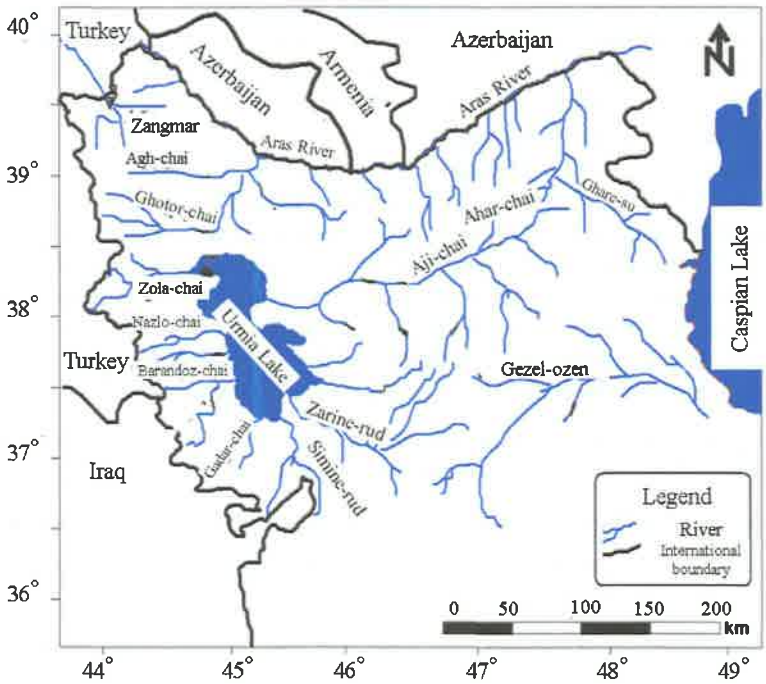
1. investigate trend of precipitation, number of rainy days, 24 h maximum rainfall, evaporation and stream flow time series on monthly basis
2. analyse stationarity of precipitation, evaporation and stream flow time series
3. make a conclusion about the possible factors effecting water resources using both trend and stationarity analysis results
4. investigate relations of selected best-fitted time series models using linear time series models, i.e., ARMA model.

2 Material and methods

2.1 Study area

West Azerbaijan province is stretched in the northwestern part of Iran between 35°58" N to 39°46" N, and between 44°03" E to 47°23" E. The total area of the province is about 43,660 square kilometres, including Lake Urmia. The rivers namely Zangmar, Agh Chai, Ghotor Chai, Zola Chai, Nazlo Chai, Shahr Chai, Barandoz Chai, Gadar Chai, Mahabad Chai, Simine Rud, and Zarine Rud flow in this province. Zangmar, Agh Chai, and Ghotor Chai rivers are located in the north of the province, and they flow into Aras River. Other rivers of the province flow into the Lake Urmia. The main rivers of northwestern part of Iran have been illustrated in Figure 1. In this study, monthly data from rain gauge (precipitation time series), climatology (evaporation time series) and hydrometric (stream flow discharge time series) stations situated in seven basins of Zola-chai, Nazlo Chai, Barandoz Chai, Gadar Chai, Mahabad Chai, Simine Rud and Zarine Rud, in the period of 1982 to 2010 were used. The 83% of historical period (1982 to 2005) was used to estimate the parameters of time series model, and 17% of remaining data (2006 to 2010) was employed to time series model verification. Since evaporation and stream flow have not been recorded after 2003 for Shahr Chai basin, applied time period was considered from 1982 to 2003, again, 82% of first part of the data (1982 to 1999) was used to determine parameters, and the rest 18% (2000 to 2003) was utilised to verify the model.

Figure 1 Most important rivers in the northwest of Iran (see online version for colours)



2.2 *Time series analysis*

The basic assumptions of time series model include homogeneity, stationarity, and normality of the data (Adeloye and Montaseri, 2002). Climate change, climate variability, human activities, catastrophic natural phenomenon and bias in recorded data, these assumptions do not satisfy in natural time series. Therefore, firstly, the validity of these assumptions should be checked, and then, if not satisfied, they would be established by some methods. In the present study, skewness test was employed to assess the normality of the used data, and in the absence of normal distribution, the data were transformed to normal distribution using equation (1). In order to realise the existence of trend and periodicity Mann-Kendall test (Kendall, 1938; Mann, 1945; Yu et al., 1993) and Fourier analysis were used, respectively. When there was trend and periodicity in the data, using the suggested method by Salas (1993), these features were eliminated from the data. In this method, with respect to monthly average and standard deviation, the data become standardised. Because the trend and periodicity in the data lead to non-stationarity in the time series (Haddad and Moravej, 2015), the purpose of removing these factors is to achieve a stationary time series in order to modelling using time series models.

$$y_t = Ln(x_t + a) \tag{1}$$

where y_t is transformed values to normal, x_t is observed values, and a is transformation parameter, which is selected in a way that converted series is closer to normal distribution.

Stationarity of transformed and standardised series was examined by ADF and KPSS tests, and after endorsement of the stationarity using the two tests, modelling was performed. Calculations related to mentioned two tests were done by E-views software.

2.2.1 *ADF stationarity test*

ADF unit root test, in the first, was provided by Dickey and Fuller (1979) and was modified by Said and Dickey (1984). ADF unit root test has emerged through estimate of ordinary least squares or regression models with existence of a linear trend. The null hypothesis (H_0) based on the non-stationarity will be accepted if the calculated t-statistic is greater than the critical value at the significance level of α. The critical values of ADF test at significance levels of 1, 5, and 10% are equal to –3.44, –2.86, and –2.57 (Dickey and Fuller, 1979). Descriptive explanation including equations can be found at Dickey and Fuller (1979), Wang et al. (2005a, 2005) and Arya and Zhang (2014).

2.2.2 *KPSS stationarity test*

This test was provided by Kwiatkowski et al. (1992) that examined the stationarity around a specific trend (KPSS-T) and stationarity around a constant level (KPSS-L). Unlike other tests of stationarity, in KPSS test null hypothesis is $H_0 = \rho < 1$, which in this condition, the series is stationary. The thresholds and calculations of this method were presented by Kwiatkowski et al. (1992). The critical values of KPSS-L method of 1%, 5%, and 10% are respectively equal to 0.739, 0.463, and 0.347, and around specific trend (KPSS-T) for 1%, 5%, and 10% are respectively equal to 0.216, 0.146, and 0.119. More information, equation and descriptive explanation can be found at Wang et al. (2005a, 2005b) and Arya and Zhang (2014).

2.2.3 Linear models of ARMA

The general form of the autoregressive (AR) moving average equation is expressible as equation (2).

$$Z_t = \varphi_1 Z_{t-1} + \varphi_2 Z_{t-2} + \ldots + \varphi_p Z_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \theta_2 \varepsilon_{t-2} - \ldots - \theta_q Z_{t-q} \tag{2}$$

where Z_t is standardised normal series, φ is coefficients of AR model, ε_t is random series of the model, p is the order of AR model, θ is coefficients of the moving average model, and q is the order of moving average model. In the equation (2), if p is zero, the moving average model is obtained, and taking q equal to zero, the AR model is achieved. In this study, auto regressive moving average (ARMA) model has been considered with different orders. Model order for each parameter was obtained using modified Akaike Information Criterion Correction (AICC for finite sample size) method (as a benchmark for selecting model). Afterwards, the efficiency of the models was assessed by portmanteau test (Salas, 1993), and finally, confirmed model by this test was used to analysis of relationship between hydrological processes.

2.2.4 Determining the model order

For determining the order of ARMA models AICC test was used. Its statistics is calculated as follows in the equation (3) (Salas, 1993).

$$AICC(p,q) = n\, Ln\left(\hat{\sigma}_\varepsilon^2\right) + \frac{2(p+q+1)n}{(n-p-q-2)} \tag{3}$$

where n is the number of data, $\hat{\sigma}_\varepsilon^2$ is variance of residuals or errors, which is obtained by equation (4) and the rest of parameters were introduced earlier.

$$\hat{\sigma}_\varepsilon^2 = \frac{s^2\left(1-\hat{\varphi}_1^2\right)}{\left(1-2\hat{\varphi}_1\,\hat{\theta}_1+\hat{\theta}_1^2\right)} \tag{4}$$

The method utilises trial and error, and one which has the lowest AICC value among the candidate models has better fit, and is selected as the best model. In this study, calculations to obtain the coefficients of the mentioned models, order of model, and AICC coefficient are performed in ITSM2000 software.

2.2.5 Goodness of fit test for linear time series models

Since portmanteau method is very useful to determine the goodness of fit with providing quantitative value, in the present study, this method was employed. To this end, firstly, the series of model residuals was obtained, and for given time lag, AR coefficients of series were calculated; then, using equation (5) portmanteau statistic was calculated:

$$Q = n\sum_{k=1}^{L} r_k^2 \tag{5}$$

where L is the maximum considered lag, r_k is AR coefficient in the k^{th} lag, and ε_t is residual series of the model. If $Q \le \chi^2(L - p - q)$ with degree of freedom of $(L - p - q)$, the test will be accepted, and residual series of the model will be considered to be independent of each other; hence, it has adequate time length for predicting (Salas et al., 1980). The rest of the parameters were introduced earlier.

3 Results

3.1 Zola Chai basin

The Mann-Kendall test employed on precipitation, number of rainy days, 24 h maximum rainfall, evaporation and stream flow time series to determine monotonic trend. The results can be seen in Table 1.

Table 1 The Mann-Kendall test's results in Zola Chai basin

Time series	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun*	*Jul.*	*Aug.*	*Sep.*	*Annual*
Precipitation	–0	–0	–0	–0	+0	+0	+0	+0	+0	+2	–0	+0	+0
Number of rainy days	+0	+0	+0	+0	+0	+0	+0	+3	+0	+3	–0	+0	+2
24 h maximum rainfall	–0	+0	–0	–0	+2	+0	+0	+0	+0	+2	–0	+0	+0
Evaporation	–0	–0	*	*	*	*	–0	–0	+0	–0	+0	–0	–0
Stream flow discharge	–3	–0	–0	–3	–3	–0	–2	–0	–0	–1	–2	–0	–1

Notes: + and – signs, indicates increasing and decreasing trend respectively, 0, 1, 2 and 3, indicates significant levels, i.e., 0 means not significant and 1, 2 and 3 means significant at 10%, 5% and 1% respectively. * indicates not applicable due frost season.

The only significant increase in precipitation occurs in Jul. which is consistent with increase of number of rainy days and 24 h maximum rainfall but this trend does not affect stream flow, as stream flow discharge in Jul. is decreasing. Annually, there is no significant monotonic trend in precipitation and evaporation, but stream flow slightly decreased. Stationarity analysis results using KPSS and ADF tests are presented in Table 2.

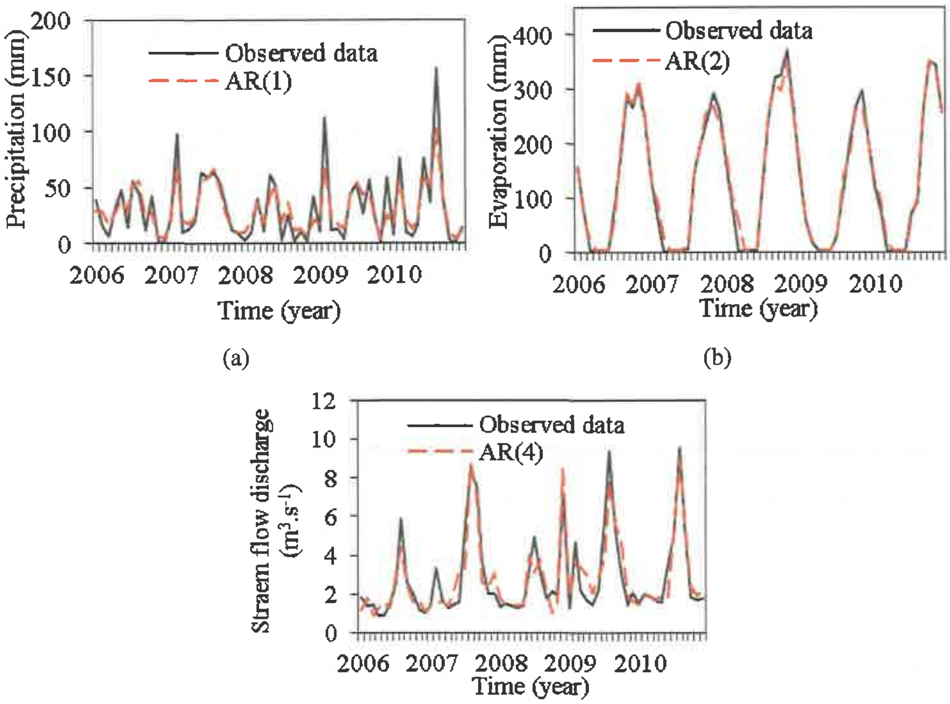
Table 2 The stationarity tests results in Zola Chai basin

Time series	*Selected lag*	*Calculated tests' statistics*			*Description*
		KPSS-T	*KPSS-L*	*ADF*	
Precipitation	13	0.12	0.22	–3.55	Stationary
Evaporation	24	0.13	0.39	–2.14	Non-stationary
Stream flow discharge	26	0.25	0.23	–3.12	Non-stationary

Considering Tables 1 and 2 results it can be concluded that precipitation and evaporation does not significantly changed in past 28 years in Zola Chai basin, but stream flow discharge of Zola Chai River decreased significantly. Due to constancy of precipitation and evaporation, decreased stream flow discharge can be a result of population growth and increase withdrawal from water resources of this basin.

The best linear time series models were fitted on monthly precipitation, evaporation and stream flow discharge time series. The verification results of models were shown in Figure 2.

Figure 2 Observed vs. forecasted data for Zola Chai basin in duration of 2006 to 2010, (a) precipitation ($Z_t = 0.1106\ Z_{t-1} + e_t$; $RMSE = 13.98$; $R^2 = 0.85$) (b) evaporation ($Z_t = 0.3248\ Z_{t-1} - 0.1021\ Z_{t-2} + e_t$; $RMSE = 15.54$; $R^2 = 0.98$) (c) stream flow discharge ($Z_t = 0.5286\ Z_{t-1} + 0.1122\ Z_{t-2} + 0.05884\ Z_{t-3} + 0.1728\ Z_{t-4} + e_t$; $RMSE = 0.86$; $R^2 = 0.83$) (see online version for colours)



(a) (b) (c)

In Zola Chai basin AR behaviour of the three processes of precipitation, evaporation, and stream flow were observed.

3.2 *Nazlo Chai basin*

The results of the Mann-Kendall test and stationarity tests are presented in Table 3 and Table 4 respectively.

The precipitation was decreased although the number of rainy days in annual scale heavily increased. It means that Nazlo Chai basin has been experienced more frequent rainy days in which it received less precipitation. This phenomenon affected water resources, i.e., stream flow of Nazlo Chai River, as it trend significantly has been decreased. Stationarity tests results were presented in Table 4. Non-stationarity of all employed time series were reported which show the significance of changes in hydrological conditions in Nazlo Chai basin. Hydrological changes can be a result of climate change, climate variability, population growth and related phenomenon.

Table 3 The Mann-Kendall test's results in Nazlo Chai basin

Time series	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun*	*Jul.*	*Aug.*	*Sep.*	*Annual*
Precipitation	–1	+0	–1	–0	+0	–0	–2	–0	+0	+0	+0	+0	–1
Number of rainy days	+0	+0	+0	+0	+0	+0	+1	+2	+2	+0	+0	+0	+3
24 h maximum rainfall	–2	+0	–2	–1	+0	+0	–0	–0	+0	+0	+0	+0	–0
Evaporation	–0	–1	*	*	*	*	+0	–0	–0	–1	+0	+0	+0
Stream flow discharge	–0	–1	–2	–2	–2	+0	–0	–0	–1	+0	+0	–0	–1

Notes: + and – signs, indicates increasing and decreasing trend respectively, 0, 1, 2 and 3, indicates significant levels, i.e., 0 means not significant and 1, 2 and 3 means significant at 10%, 5% and 1% respectively. * indicates not applicable due frost season.

Table 4 The stationarity tests results in Nazlo Chai basin

Time series	*Selected lag*	*Calculated tests' statistics*			*Description*
		KPSS-T	*KPSS-L*	*ADF*	
Precipitation	25	0.16	0.22	–4.28	Non-stationary
Evaporation	12	0.26	0.39	–2.14	Non-stationary
Stream flow discharge	26	0.11	0.22	–2.44	Non-stationary

Best linear time series models fitted on precipitation, evaporation and stream flow time series are shown in Figure 3.

Figure 3 Observed vs. forecasted data for Nazlo Chai basin in duration of 2006 to 2010, (a) precipitation ($Z_t = 0.1006\ Z_{t-1} + e_t$; RMSE = 13.71; $R^2 = 0.81$) (b) evaporation ($Z_t = 0.4507\ Z_{t-1} + e_t$; RMSE = 16.64; $R^2 = 0.96$) (c) stream flow discharge ($Z_t = 0.8083\ Z_{t-1} - 0.07895\ Z_{t-2} + 0.1376\ Z_{t-3} + e_t$; RMSE = 2.74; $R^2 = 0.92$) (see online version for colours)

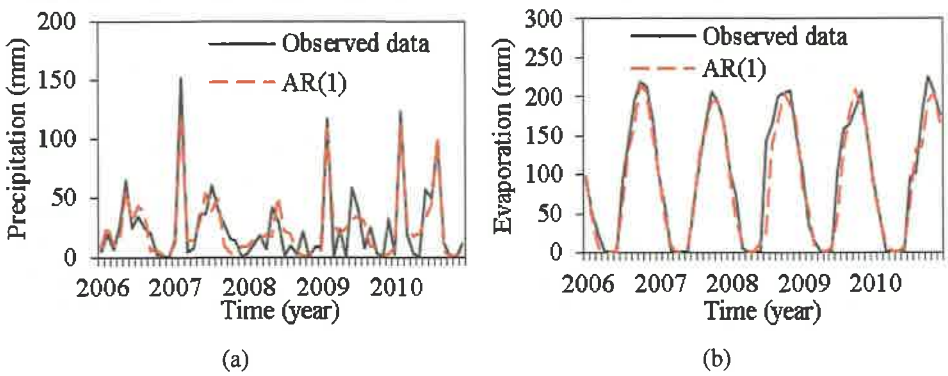
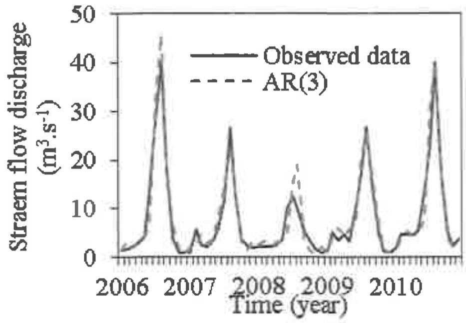


Figure 3 Observed vs. forecasted data for Nazlo Chai basin in duration of 2006 to 2010, (a) precipitation ($Z_t = 0.1006\ Z_{t-1} + e_t$; RMSE = 13.71; $R^2 = 0.81$) (b) evaporation ($Z_t = 0.4507\ Z_{t-1} + e_t$; RMSE = 16.64; $R^2 = 0.96$) (c) stream flow discharge ($Z_t = 0.8083\ Z_{t-1} - 0.07895\ Z_{t-2} + 0.1376\ Z_{t-3} + e_t$; RMSE = 2.74; $R^2 = 0.92$) (continued) (see online version for colours)



(c)

In Nazlo Chai basin similar to Zola-Chai basin, also, AR behaviour of all three hydrological processes of precipitation, evaporation, and stream flow were observed.

3.3 *Shahr Chai basin*

Table 5 presents the results of Mann-Kendall trend test in Shahr Chai basin.

Table 5 The Mann-Kendall test's results in Shahr Chai basin

Time series	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun*	*Jul.*	*Aug.*	*Sep.*	*Annual*
Precipitation	–0	+0	–0	+1	+0	–0	+0	–0	+0	+0	+0	+0	–0
Number of rainy days	–0	–0	–0	+0	+0	–2	+0	–0	+0	–0	–0	–0	–0
24 h maximum rainfall	–1	–0	–0	+0	–0	–0	–0	–0	–0	+0	–0	–0	–2
Evaporation	+3	+3	*	*	*	+1	–1	+1	+3	+3	+3	+3	+3
Stream flow discharge	–2	–2	–3	–0	–0	–0	–0	–0	–0	–0	–0	–1	–0

Notes: + and – signs, indicates increasing and decreasing trend respectively, 0, 1, 2 and 3, indicates significant levels, i.e., 0 means not significant and 1, 2 and 3 means significant at 10%, 5% and 1% respectively. * indicates not applicable due frost season.

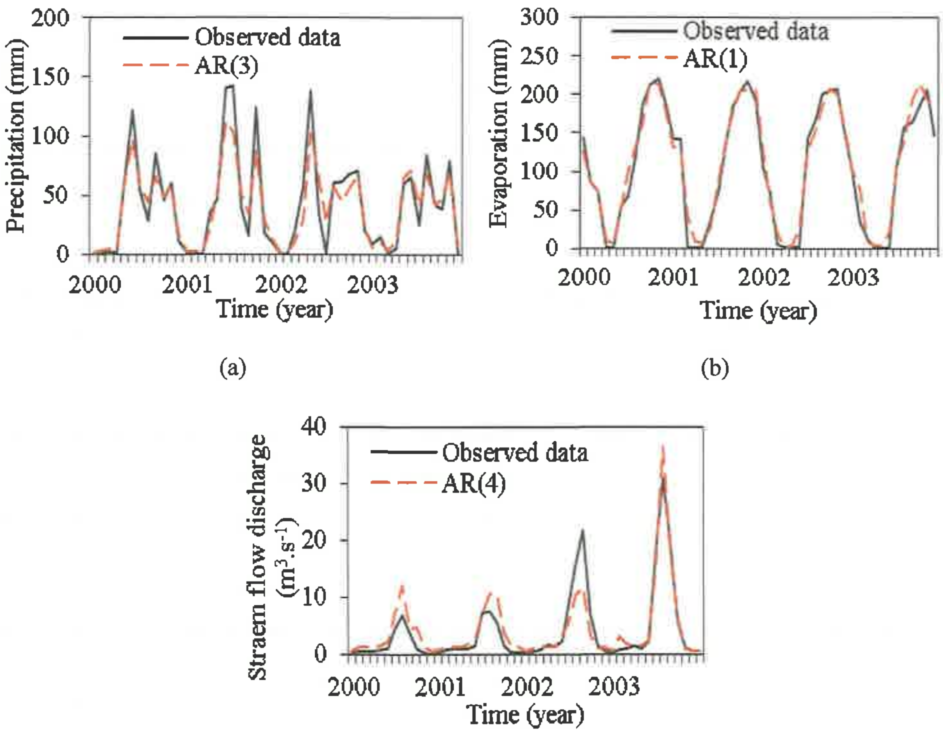
The most important point in Table 5 is significant increase of evaporation at 1% in annual scale and almost all months. The interesting fact is this severe increase is not followed by precipitation or stream flow discharge. The increase of evaporation is because of increase in temperature, as some researches indicate increase in temperature in Shahr Chai basin (Nazeri-Tahroudi et al., 2014). The significant decreasing trend in Oct., Nov. and Dec. was also reported by Dinpashoh et al. (2010). Stationarity analysis results are presented in Table 6.

Table 6 The stationarity tests results in Shahr Chai basin

Time series	*Selected lag*	*Calculated tests' statistics*			*Description*
		KPSS-T	*KPSS-L*	*ADF*	
Precipitation	24	0.12	0.41	–6.26	Stationary
Evaporation	13	0.42	0.86	–1.26	Non-stationary
Stream flow discharge	25	0.23	0.12	–2.75	Non-stationary

The results of fitted linear time series verification have been illustrated in Figure 4.

Figure 4 Observed vs. forecasted data for Shahr Chai basin in duration of 2000 to 2003, (a) precipitation ($Z_t = 0.03018\ Z_{t-1} + 0.1739\ Z_{t-2} + 0.1680\ Z_{t-3} + e_t$; $RMSE = 16.10$; $R^2 = 0.88$) (b) evaporation ($Z_t = 0.4415\ Z_{t-1} + e_t$; $RMSE = 17.88$; $R^2 = 0.95$) (c) stream flow discharge ($Z_t = 0.6763\ Z_{t-1} - 0.1297\ Z_{t-2} + 0.1078\ Z_{t-3} + 0.09539\ Z_{t-4} + e_t$; $RMSE = 2.34$; $R^2 = 0.86$) (see online version for colours)



(a) (b) (c)

In this basin, same as Nazlo Chai and Shahr Chai basins, AR behaviour of all three hydrological processes were observed.

3.4 Barandoz Chai basin

Trend analysis results have been presented in Table 7. Decreasing trend of evaporation and stream flow in annual scale observed in Barandoz Chai basin. Stream flow of Barandoz Chai River has been decreased in almost all months in past 28 years, which is not in consistent with evaporation trend. It means that other factors affect stream flow discharge in Barandoz Chai basin. Population growth, land use changes and increase in water withdrawal can be listed as main factors.

Table 7 The Mann-Kendall test's results in Barandoz Chai basin

Time series	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun*	*Jul.*	*Aug.*	*Sep.*	*Annual*
Precipitation	–2	–0	–2	+0	+0	+0	+0	–0	–0	–0	–0	+0	–0
Number of rainy days	–1	+0	–2	–0	+0	+0	+0	–0	+0	–0	+0	–0	–0
24h maximum rainfall	–2	+0	–2	+0	+0	+0	–0	–0	–0	+0	–0	+0	–0
Evaporation	–2	–0	*	*	*	*	–2	–3	–2	–3	–2	–2	–3
Stream flow discharge	–2	–0	–3	–2	–2	+0	–0	–0	–2	–2	–3	–2	–2

Notes: + and – signs, indicates increasing and decreasing trend respectively, 0, 1, 2 and 3, indicates significant levels, i.e., 0 means not significant and 1, 2 and 3 means significant at 10%, 5% and 1% respectively. * indicates not applicable due frost season.

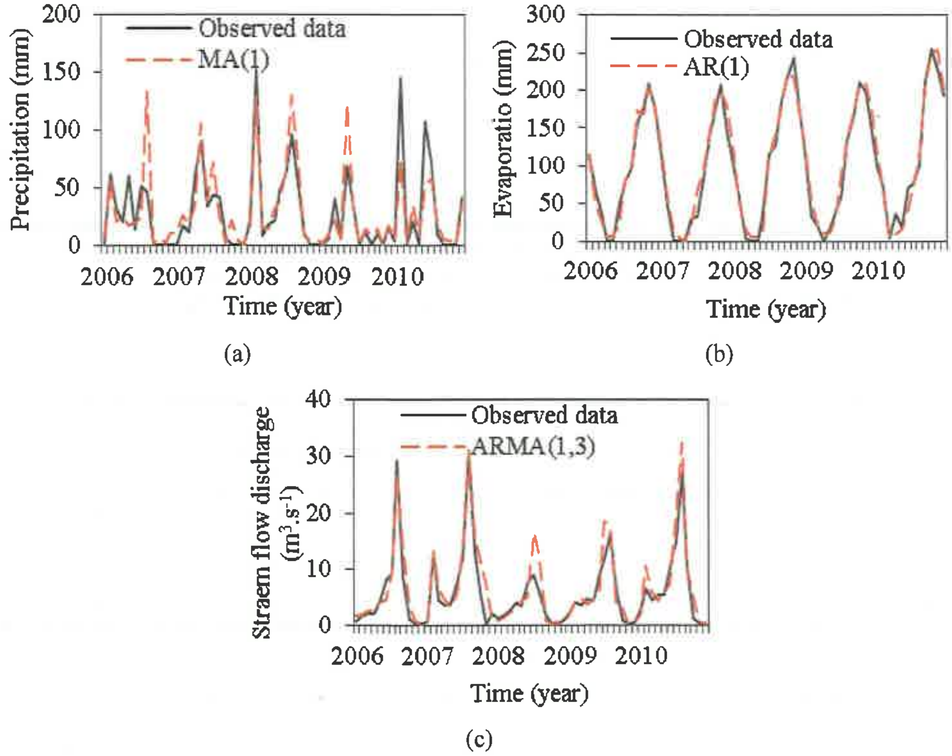
According to Table 8, which represents stationarity analysis of precipitation, evaporation and stream flow, it can be concluded that climate variability or climate change affected Barandoz Chai basin as mentioned time series are non-stationary.

Table 8 The stationarity tests results in Barandoz Chai basin

Time series	*Selected lag*	*Calculated tests' statistics*			*Description*
		KPSS-T	*KPSS-L*	*ADF*	
Precipitation	24	0.18	0.32	–2.64	Non-stationary
Evaporation	12	0.28	1.64	–1.04	Non-stationary
Stream flow discharge	25	0.08	1.04	–2.04	Non-stationary

The results of time series modelling of three hydrological processes have been illustrated in Figure 5. In Barandoz Chai basin stochastic behaviour was seen in precipitation and stream flow, especially precipitation shows very weak relationship with stochastic residual of one month lag demonstrates random form of precipitation in the region. So, fitting model of precipitation reflects weaker accuracy than other basins.

Figure 5 Observed vs. forecasted data for Barandoz Chai basin in duration of 2006 to 2010, (a) precipitation ($Z_t = e_t + 0.04627\ e_{t-1}$; $RMSE = 21.56$; $R^2 = 0.65$) (b) evaporation ($Z_t = 0.4047\ Z_{t-1} + e_t$; $RMSE = 14.85$; $R^2 = 0.96$) (c) stream flow discharge ($Z_t = 0.9441\ Z_{t-1} + e_t - 0.3233\ e_{t-1} - 0.1103\ e_{t-2} - 0.1218\ e_{t-3}$; $RMSE = 2.66$; $R^2 = 0.88$) (see online version for colours)



3.5 *Gadar Chai basin*

Table 9 and Table 10 demonstrate Mann-Kendall and Stationarity results of Gadar Chai basin, respectively. An important point in Table 9 is decreasing trend in both precipitation and stream flow discharge. According to non-stationarity of these two processes reported in Table 10, it can be concluded that decreasing trend in available water resources (i.e., stream flow discharge) in Gadar Chai basin is a consequence of negative trend of precipitation. In other word, abating available water resources is caused by climate change or climate variability.

Verification results of selected linear time series models are presented in Figure 6. In Gadar Chai basin, all three hydrological processes including precipitation, evaporation, and stream flow showed AR behaviour.

Table 9 The Mann-Kendall test's results in Gadar Chai basin

Time series	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun*	*Jul.*	*Aug.*	*Sep.*	*Annual*
Precipitation	–0	–0	–2	–1	–0	–0	+0	–0	–0	+1	–0	+2	–1
Number of rainy days	–0	+0	–0	–0	–0	+0	+0	+0	+0	+0	–0	+2	+0
24 h maximum rainfall	–1	–0	–2	–2	+0	–0	–0	–0	–0	+0	–0	+2	–2
Evaporation	+0	+2	*	*	*	*	+0	+0	+0	+0	+0	+0	+0
Stream flow discharge	–2	–0	–2	–0	–0	+0	–1	–0	–1	–0	–0	–3	–1

Notes: + and – signs, indicates increasing and decreasing trend respectively, 0, 1, 2 and 3, indicates significant levels, i.e., 0 means not significant and 1, 2 and 3 means significant at 10%, 5% and 1% respectively. * indicates not applicable due frost season.

Table 10 The stationarity tests results in Gadar Chai basin

Time series	*Selected lag*	*Calculated tests' statistics*			*Description*
		KPSS-T	*KPSS-L*	*ADF*	
Precipitation	24	0.19	0.32	–3.10	Non-stationary
Evaporation	25	0.10	0.43	–2.10	Non-stationary
Stream flow discharge	23	0.09	0.33	–2.04	Non-stationary

Figure 6 Observed vs. forecasted data for Gadar Chai basin in duration of 2006 to 2010, (a) precipitation ($Z_t = 0.09750\ Z_{t-1} + 0.1296\ Z_{t-2} + e_t$; $RMSE = 18.72$; $R^2 = 0.82$) (b) evaporation ($Z_t = 0.3101\ Z_{t-1} + 0.1805\ Z_{t-2} - 0.07062\ Z_{t-3} - 0.009240\ Z_{t-4} + 0.08769\ Z_{t-5} + 0.01534\ Z_{t-6} - 0.03589\ Z_{t-7} - 0.01035\ Z_{t-8} + 0.01669\ Z_{t-9} + 0.1604\ Z_{t-10} + 0.1505\ Z_{t-11} + e_t$; $RMSE = 19.47$; $R^2 = 0.97$) (c) stream flow discharge ($Z_t = 0.6948\ Z_{t-1} + 0.08733\ Z_{t-2} + e_t$; $RMSE = 3.29$; $R^2 = 0.88$) (see online version for colours)

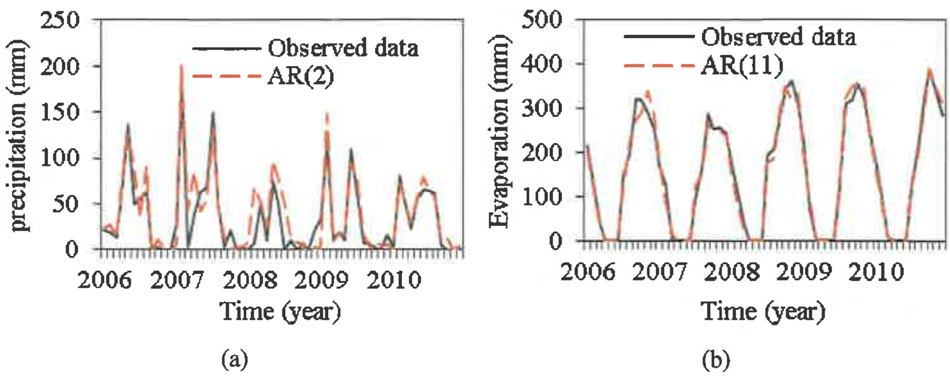
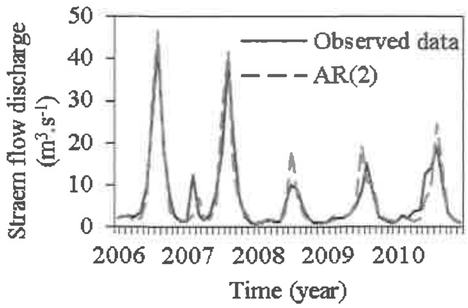


Figure 6 Observed vs. forecasted data for Gadar Chai basin in duration of 2006 to 2010, (a) precipitation ($Z_t = 0.09750\ Z_{t-1} + 0.1296\ Z_{t-2} + e_t$; $RMSE = 18.72$; $R^2 = 0.82$) (b) evaporation ($Z_t = 0.3101\ Z_{t-1} + 0.1805\ Z_{t-2} - 0.07062\ Z_{t-3} - 0.009240\ Z_{t-4} + 0.08769\ Z_{t-5} + 0.01534\ Z_{t-6} - 0.03589\ Z_{t-7} - 0.01035\ Z_{t-8} + 0.01669\ Z_{t-9} + 0.1604\ Z_{t-10} + 0.1505\ Z_{t-11} + e_t$; $RMSE = 19.47$; $R^2 = 0.97$) (c) stream flow discharge ($Z_t = 0.6948\ Z_{t-1} + 0.08733\ Z_{t-2} + e_t$; $RMSE = 3.29$; $R^2 = 0.88$) (continued) (see online version for colours)



(c)

3.6 *Mahabad Chai basin*

The results of Mann-Kendall test are presented in Table 11 and the results of stationarity tests can be seen in Table 12. Negative trend in stream flow time series was observed, buy there is no significant trend in precipitation and evaporation time series. Same conclusion like Barandoz Chai basin can perform for Mahabad Chai to explain the reasons of solo trend of stream flow.

Table 11 The Mann-Kendall test's results in Mahabad Chai basin

Time series	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun*	*Jul.*	*Aug.*	*Sep.*	*Annual*
Precipitation	−2	+0	−1	−0	−0	−0	−0	+0	−0	−0	+0	+0	−0
Number of rainy days	−0	+0	−0	−0	−0	−0	−0	−0	+0	+0	+0	+0	−2
24 h maximum rainfall	−2	+0	−0	−1	−0	+0	+0	−0	−0	−0	+0	+0	+0
Evaporation	+0	−0	+1	*	*	*	−0	−0	+0	+0	+3	+1	+0
Stream flow discharge	−0	−0	−2	−2	−1	−1	−2	−1	−2	−0	−0	−0	−2

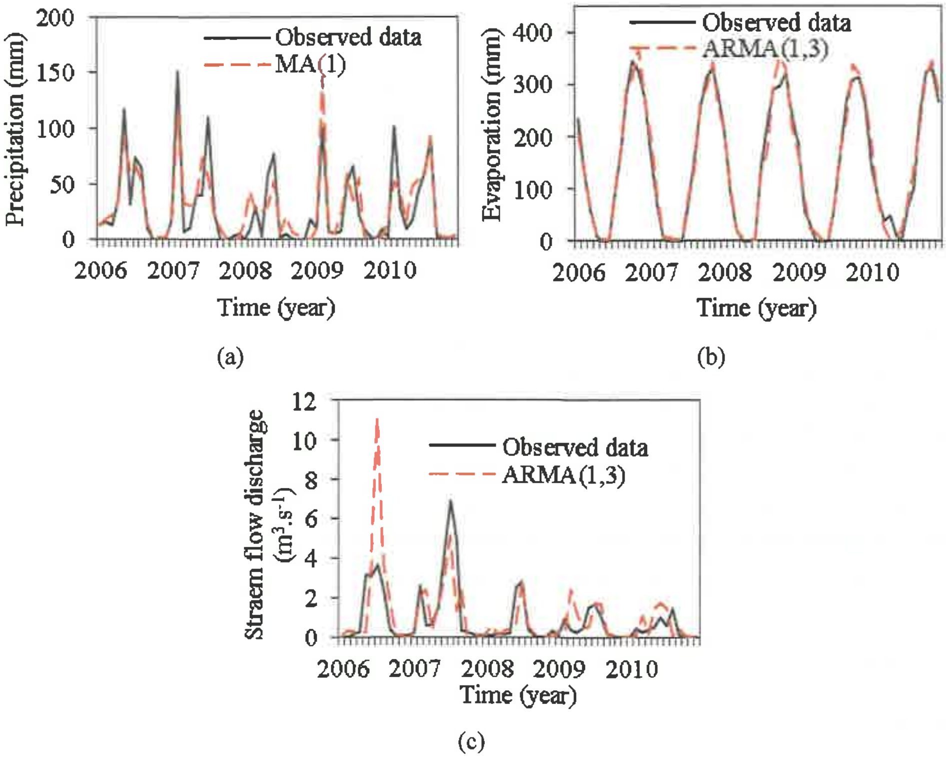
Notes: + and − signs, indicates increasing and decreasing trend respectively, 0, 1, 2 and 3, indicates significant levels, i.e., 0 means not significant and 1, 2 and 3 means significant at 10%, 5% and 1% respectively. * indicates not applicable due frost season.

Table 12 The stationarity tests results in Mahabad Chai basin

Time series	*Selected lag*	*Calculated tests' statistics*			*Description*
		KPSS-T	*KPSS-L*	*ADF*	
Precipitation	24	0.12	0.36	−2.91	Non-stationary
Evaporation	12	0.20	0.62	−3.42	Stationary
Stream flow discharge	13	0.10	0.74	−10.42	Non-stationary

Verification results of selected linear time series models of Mahabad Chai basin are presented in Figure 6. Existence of MA component in all three processes proves to be stochastic for all processes, particularly precipitation, which is totally stochastic. Moreover, stochastic behaviour of precipitation seems to affect stream flow of the river, and encourage its randomness to some extent.

Figure 7 Observed vs. forecasted data for Mahabad Chai basin in duration of 2006 to 2010, (a) precipitation ($Z_t = e_t + 0.03579\ e_{t-1}$; $RMSE = 18.77$; $R^2 = 0.72$) (b) evaporation ($Z_t = 0.5479\ Z_{t-1} + e_t - 0.1740\ e_{t-1} - 0.02628\ e_{t-2} - 0.1350\ e_{t-3}$; $RMSE = 20.90$; $R^2 = 0.97$) (c) stream flow discharge ($Z_t = 0.8550\ Z_{t-1} + e_t - 0.06962\ e_{t-1} - 0.1446\ e_{t-2} - 0.2382\ e_{t-3}$; $RMSE = 1.36$; $R^2 = 0.41$) (see online version for colours)



3.7 Simine Rud basin

Table 13 and Table 14 show Mann-Kendall and stationarity results of Simine Rud basin, respectively. The strong positive trend in evaporation and negative trend in stream flow discharge reported. Positive trend of evaporation is may the effect of positive trend in temperature. The negative trend in stream flow is partly because of evaporation trend. stationarity analysis results is also indicates significant change in evaporation and stream flow.

Table 13 The Mann-Kendall test's results in Simine Rud basin

Time series	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun*	*Jul.*	*Aug.*	*Sep.*	*Annual*
Precipitation	–1	+0	–3	–0	–0	–0	+0	–0	+0	+1	+0	+2	+0
Number of rainy days	–0	+0	–0	–0	+0	–0	+1	–0	+1	+1	+0	+3	+0
24 h maximum rainfall	–1	+0	–3	+0	+0	–0	+0	+0	+1	+0	+1	+2	–0
Evaporation	+2	+0	*	*	*	*	+1	+1	+1	+2	+3	+3	+3
Stream flow discharge	–3	–2	–3	–2	–0	–0	–3	–3	–3	–3	–2	–3	–3

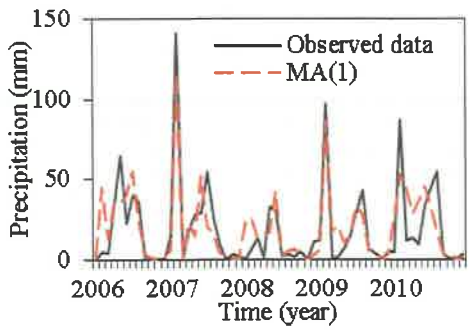
Notes: + and – signs, indicates increasing and decreasing trend respectively, 0, 1, 2 and 3, indicates significant levels, i.e., 0 means not significant and 1, 2 and 3 means significant at 10%, 5% and 1% respectively. * indicates not applicable due frost season.

Table 14 The stationarity tests results in Simine Rud basin

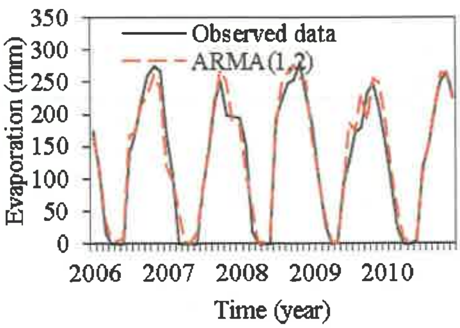
Time series	*Selected lag*	*Calculated tests' statistics*			*Description*
		KPSS-T	*KPSS-L*	*ADF*	
Precipitation	12	0.07	0.09	–3.82	Stationary
Evaporation	12	0.51	0.56	–0.23	Non-stationary
Stream flow discharge	16	0.13	0.21	–3.44	Non-stationary

Verification of fitted models on various hydrological processes in Simine Rud basin is shown in Figure 8. In this basin, stochastic and fluctuating behaviour of precipitation is observed. MA component exists in three processes of Simine Rud basin, which show stochastic behaviour. Especially, precipitation that is completely stochastic. It appears that randomness of precipitation has affected the stream flow discharge, and a proportion of stochastic behaviour of discharge comes from precipitation.

Figure 8 Observed vs. forecasted data for Simine Rud basin in duration of 2006 to 2010, (a) precipitation ($Z_t = e_t + 0.06700\ e_{t-1}$; $RMSE = 15.21$; $R^2 = 0.65$) (b) evaporation ($Z_t = 0.6867\ Z_{t-1} + e_t - 0.3196\ e_{t-1}$; $RMSE = 23.30$; $R^2 = 0.94$) (c) stream flow discharge ($Z_t = 0.8585\ Z_{t-1} + e_t - 0.3330\ e_{t-1} - 0.1546\ e_{t-2}$; $RMSE = 2.69$; $r^2 = 0.95$) (see online version for colours)

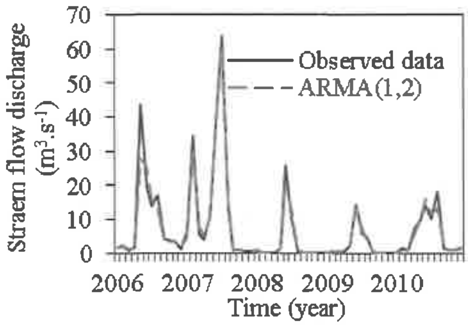


(a)



(b)

Figure 8 Observed vs. forecasted data for Simine Rud basin in duration of 2006 to 2010, (a) precipitation ($Z_t = e_t + 0.06700\ e_{t-1}$; $RMSE = 15.21$; $R^2 = 0.65$) (b) evaporation ($Z_t = 0.6867\ Z_{t-1} + e_t - 0.3196\ e_{t-1}$; $RMSE = 23.30$; $R^2 = 0.94$) (c) stream flow discharge ($Z_t = 0.8585\ Z_{t-1} + e_t - 0.3330\ e_{t-1} - 0.1546\ e_{t-2}$; $RMSE = 2.69$; $r^2 = 0.95$) (continued) (see online version for colours)



(c)

3.8 *Zarine Rud basin*

Table 9 and Table 10 demonstrate Mann-Kendall and Stationarity results of Gadar Chai basin, respectively. Same as Simine Rud, there is a negative trend in stream flow andpositive tren in evaporation. The negative trend in stream flow is partly because of evaporation trend. And the stationarity analysis is also leads to same results for Zarine Rud basin. So, it can be concluded that these two adjacent basins have been experienced same hydrological conditions climatic wise. Verification of fitted models on various hydrological processes in Zarine Rud basin is shown in Figure 8.

Table 15 the Mann-Kendall test's results in Zarine Rud basin

Time series	*Oct.*	*Nov.*	*Dec.*	*Jan.*	*Feb.*	*Mar.*	*Apr.*	*May*	*Jun*	*Jul.*	*Aug.*	*Sep.*	*Annual*
Precipitation	+0	–0	–0	+0	+0	–0	–0	–0	+0	+0	+0	+2	–0
Number of rainy days	+0	+0	–0	+0	–0	+0	–0	–0	+1	+0	+0	+2	+0
24 h maximum rainfall	+0	+0	–0	–0	+1	+0	+0	–0	+0	+0	+0	+2	–0
Evaporation	+2	–0	*	*	*	*	+0	+1	+1	+1	+3	+3	+2
Stream flow discharge	–3	–3	–3	–3	–3	–0	–0	–0	–0	–0	–0	–3	–1

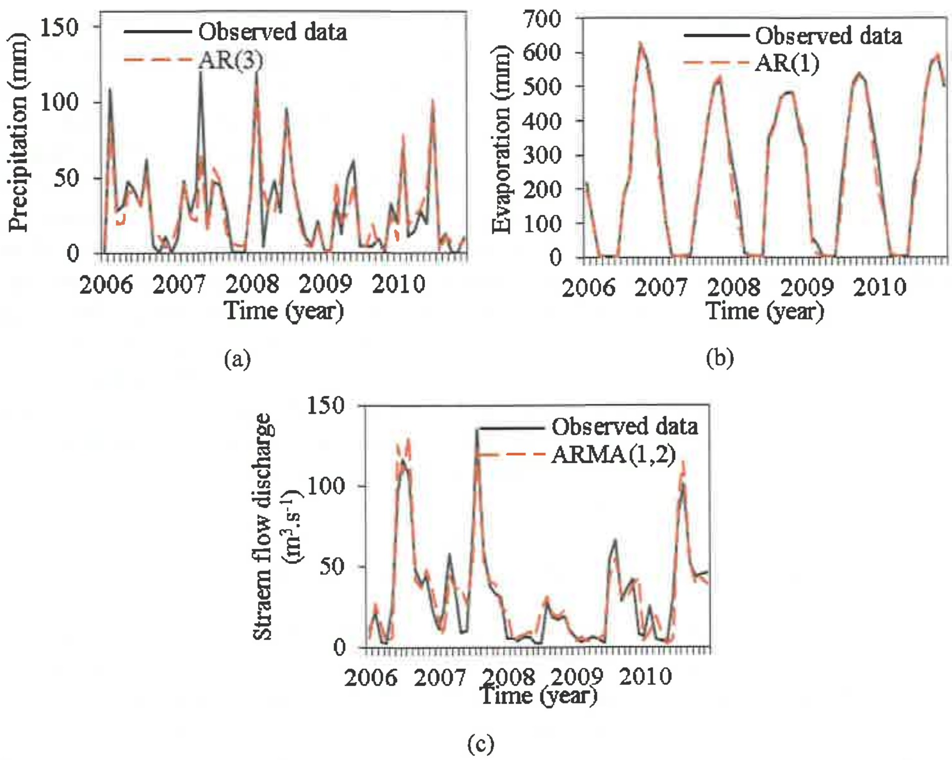
Notes: + and – signs, indicates increasing and decreasing trend respectively, 0, 1, 2 and 3, indicates significant levels, i.e., 0 means not significant and 1, 2 and 3 means significant at 10%, 5% and 1% respectively. * indicates not applicable due frost season.

Table 16 The stationarity tests results in Zarine Rud basin

Time series	*Selected lag*	*Calculated tests' statistics*			*Description*
		KPSS-T	*KPSS-L*	*ADF*	
Precipitation	26	0.06	0.06	–3.51	Stationary
Evaporation	25	0.58	0.96	–1.36	Non-stationary
Stream flow discharge	14	0.15	0.36	–2.32	Non-stationary

AR behaviour was observed in precipitation, evaporation, and stream flow discharge in Zarine Rud basin. AR of stream flow discharge with one month lag is an indicator of memory of stream flow discharge in this river, however, moving average component as a stochastic component is also observed in Zarine Rud stream flow discharge. Existence of MA behaviour in large basins like Zarine Rud, can be a result of complex well-developed stream branches or because existence of nonlinearity in stream flow time series (mostly as a result of nonlinear relation of precipitation-run-off processes) and inability of linear models to cop nonlinearity, which can be seen as stochastic components in linear models.

Figure 9 Observed vs. forecasted data for Zarine Rud basin in duration of 2006 to 2010, (a) precipitation ($Z_t = 0.09827\ Z_t + 0.1748\ Z_{t-1} + 0.1504\ Z_{t-2} + e_t$; $RMSE = 12.94$; $R^2 = 0.82$) (b) evaporation ($Z_t = 0.2461\ Z_{t-1} + e_t$; $RMSE = 25.31$; $R^2 = 0.98$) (c) stream flow discharge ($Z_t = 0.8756\ Z_{t-1} + e_t - 0.2763\ e_{t-1} - 0.1100\ e_{t-2}$; $RMSE = 11.69$; $R^2 = 0.87$) (see online version for colours)



4 Discussion

The obtained results of present study can be discussed from following aspects:

4.1 Climate change in Lake Urmia basin

In current research changes in precipitation, evaporation and stream flow time series of 8 sub basins of Lake Urmia basin during a long 28 years period were investigated using trend and stationarity analysis. Results indicate some non-stationarity in precipitation and evaporation which simply may consider as a sign of climate change or climate variability. Decreasing in stream flow discharge over 28 years in almost all studied sub basins can partly be a result of climate change and trends observed in precipitation and evaporation, but certainly population growth, land use changes and increase in water withdrawal are another factors to blame for.

4.2 Investigation the relationship between different models of processes in a basin

According to physical base of ARMA models provided by Salas et al. (1980), the precipitation has been considered independently and stochastically. If this assumption is not true in a basin, it is expected that the MA component of stream flow discharge model would be eliminated or washed out. This case has occurred in Zola-chai, Nazlo Chai, Shahr Chai, and Gadar Chai basins. In these basins, behaviour of precipitation and evaporation is AR. It is observed that the stream flow discharge behaviour also follows AR models that have greater lags than precipitation and evaporation lags. In Barandoz Chai, Mahabad Chai, Simine Rud basins, behaviour of precipitation is stochastic and follows the MA model, which is specific to stochastic processes. In these basins, stochastic behaviour of precipitation affects stream flow behaviour, and it is observed that stochastic term of MA is also appear in the stream flow; it leads to decrease the memory of stream flow discharge. The fact that the MA component in stream flow discharge is greater than MA component in precipitation indicates that during the process of producing stream flow discharge from precipitation, the stochastic factors have had roles. In large basins, due to their large area and developed drainage network, it is expected that the process of producing runoff from precipitation would be more complex. This situation has been observed in Zarine Rud basin. In this basin, precipitation and evaporation are regular and AR, while obtained stream flow model has stochastic component. The reason of this issue can be the complicated process of converting precipitation to runoff in large basins.

4.3 The similarity between models in adjacent basins with similar climate

Hydrologic processes behaviour in western part of the province follows an AR models, however, in southern part of the province, this behaviour is transformed to ARMA models. The stochastic component of model in south of the province has more weight than west of the province. West Azerbaijan province can be categorised into two homogenous climate clusters. West of the province was considered as one climate, and south of the province has different climate; it means that Zola-chai, Nazlo Chai, and Shahr Chai was taken as one cluster into account and Gadar Chai, Mahabad Chai, Simine

Rud, and Zarine Rud as one cluster. The obtained results of this study also showed that time series models of hydrologic processes in homogeneous climate basins are similar to each other. Hence it seems that there is a correlation between time series models and the region climate. Moreover, Barandoz Chai, Mahabad Chai, Simine Rud and Zarine Rud have more springs and groundwater discharge to surface system than the other basins, which encourage the weight of both AR and MA component of an ARMA model. This is concord the physical base of ARMA models in basins proposed by Salas et al. (1980).

4.4 Comparison of autocorrelation of processes

Stream flow, evaporation and precipitation had the highest autocorrelation respectively. Low autocorrelation value of precipitation shows low memory of this process which is compatible with stochastic nature of precipitation. On the other hand, high autocorrelation value represents memory of stream flow which is because of snow storage of basin and ground water discharge. Evaporation in middle shows a medium memory which is because of temperature fluctuation over seasons, in other words, it can be said that the main phenomena that govern evaporation is season fluctuation which simply can be modelled with Fourier analysis, and not with time series models. In this study this feature was removed with standardisation. So, the memory of evaporation was less than stream flow.

5 Conclusions

In this study, the relationship between time series models of various hydrological parameters was investigated in the West Azerbaijan province basins, and acquired results were comprehensively discussed. In summary, the results indicated a significant relationship between the models and trends of different processes. As a result, the simultaneous analysing of different processes leads to a better understanding of sophisticated hydrological cycle process in the basin scale. Moreover, knowing the dominant model on precipitation and evaporation process can improve the selection of an appropriate model in order to simulation and prediction of stream flow. In addition, understanding the governing factors on stream flow discharge using statistical methods can lead to better water resources management and it certainly helps to establish realistic policies.

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