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# Analysis of Hydroclimatic Trends in the Atrak River Basin, North Khorasan, Iran (1975–2008)

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**Abstract**

Hydrologic regime is highly dependent on climate change, as hydrologic cycle components are directly influenced by climatic conditions. This paper analyzes the impacts of climate change on the hydrologic regime of the Atrak River basin in the northeast of Iran. The river drains to the Caspian Sea in its southeastern coasts. The data collected at 11 hydrometeorological stations were examined to detect trends in hydroclimatological variables. Ten variables including annual mean discharge, annual maximum discharge, annual precipitation, maximum daily precipitation, annual minimum, mean and maximum temperatures, diurnal temperature range, annual pan evaporation and annual potential evapotranspiration during 1975–2008 were analyzed using Mann-Kendall non-parametric test. The long term observations of annual mean discharge at 8 hydrometric stations were analyzed to reveal indications of increasing or decreasing trends. Then, the long term records of precipitation, temperature, pan evaporation and potential evapotranspiration were examined to detect signs of climate change. Finally, the relationship between trends in streamflow and meteorological variables was investigated. The results indicate that although the annual mean discharge at all stations across the Atrak River basin is decreasing, but the decrease is statistically significant at only 6 stations (75 percent of stations). However, there is no evidence of significant increasing or decreasing trends in the precipitation variables. Analyses of temperature and evaporation variables show increasing trends in most of the stations. Therefore, it is concluded that decreasing trends of mean annual discharge is most likely related to an increase in the evaporative power of atmosphere.

***Keywords***: Atrak, climate change, discharge, Mann-Kendall, trend analysis

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## 1. Introduction

Since water is the basic element of the life support system of the planet, water resources management is a key issue in sustainable development of all ecosystems. Water availability is important for human health, economic activity, ecosystem function and geophysical processes (Milly *et al.*, 2005). On the other hands, water and climate are intimately linked (Kundzewicz, 2008). This is while global climate change has already been observed and even a stronger change is projected for the future using climate models (Parry *et al.*, 2007). Therefore, it is of utmost importance to understand the likely impacts of the ongoing and projected climate change on the water resources and water availability in a region as well as its spatial and temporal variations.

The Third Assessment Report (TAR) by the Intergovernmental Panel on Climate Change (IPCC) indicated that due to large amounts of greenhouse gas emissions, mean global temperature has increased by 0.6±0.2 °C during the 20th century and it has also been predicted that the global temperature will further increase by 1.4 to 5.8 °C during the 21st century. These predictions are based on a number of climate models and for the full range of 35 SRES scenarios (McCarthy *et al.,* 2001). According to the fourth and the most recent assessment report by IPCC (Parry *et al.,* 2007), annual average river runoff is projected to increase by 10–40% at high latitudes and in some wet tropical areas, and to decrease by 10 – 30% over some dry regions at mid-latitudes and in dry tropics by midcentury. Considering the precipitation changes, the same IPCC report has also predicted general increases of 10–20% of precipitation at latitudes above 45° and within 5° of the equator but decreases of 5–20% between latitudes of 5 and 40°. Therefore, there is a general belief that global warming will lead to changes in spatial and temporal distributions of regional water resources and the global hydrological cycles (Qader, 2002; Labat *et al.*, 2004). Due to the importance of the topic, during the last decades many researchers have carried out many regional and a number of national streamflow trend studies, particularly in the North America and Europe (Robson *et al.,* 1998; Lins & Slack, 1999; Douglas *et al.,* 2000; Zhang *et al.,* 2001; Burn & Elnur, 2002; Yue & Pilon, 2003; Birsan *et al.*, 2005; Abdul Aziz & Burn, 2006; Han, 2007). Most of these studies tried to link the observed trends in streamflow to changes in climate variables, particularly the precipitation. However, due to great diversity in scale, geographic location, included parameters, and the length of study periods the results are contentious. Since the pattern and impact of climate change vary from one geographic location to the other, it is necessary to carry out local and regional studies to detect the direction and magnitude of climate change as well as to understand their impact on the water resources of an area or region. Regardless of the direction and magnitude of changes in climate variables, it is believed that the hydrological cycle of the planet has been accelerated (Ohmura & Wild, 2002). The intensification of hydrological cycle has resulted in extreme floods and droughts.

Floods and droughts are two frequently occurring natural hazards within the Atrak River basin (Hodaei, 2008) where shortage and inappropriate spatial and temporal distribution of water resources is an inherent issue. Unfortunately, local documentations and reports indicate an increasing trend in the frequency and severity of floods and droughts and the damages induced by them. Some researchers believe that these increasing trends are most likely related to the global climate change impacts (Sheikh & Bahremand, 2009). In this regard, Sheikh and Bahremand (2011) studied the relationship between discharge and precipitation variables at six hydroclimatic stations in the upper section of the Atrak River basin. They reported that despite a significant decreasing trend in the mean annual and seasonal discharge at the studied stations, there is no clear and statistically proved relationship between decreasing trend of discharge and precipitation. Therefore, in this study it was decided to carry out a more thorough analysis across the whole basin considering more climatic variables.

## 2. Materials and methods

### Study area description

This study was carried out within the Atrak River basin in northeast of Iran (Fig. 1). The Atrak River basin locates between eastern longitudes of 54° and 59° 04′ and northern latitudes of 38° 17′ and 38° 57′. Elevation ranges from -22 m a.s.l at the Caspian Sea southeastern coast to 2903 m a.s.l. at the highest point in the easternmost parts of the basin. From physiographic point of view, the Atrak River basin has two distinct sections: mountains and flat plains. The precipitation pattern varies depending on the physiographic condition. In higher mountains it occurs mostly as snow in autumn and winter and as rainfall in other seasons. In plains it mostly occurs as rainfall except in winter seasons which often falls as snow. This precipitation pattern influences the hydrologic behavior of the river basin which fluctuates seasonally. Flash floods happen during May to October and seasonal flows start from mid-autumn till mid-spring of the next year.

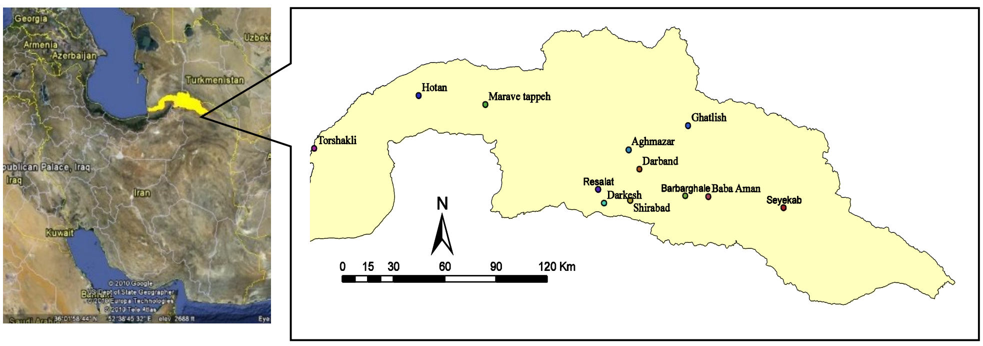


**Figure 1.** Location of the study area and hydro climatological stations.

The Atrak River is one of the longest rivers of the country with a total length of about 520 km and drainage area of approximately 25627 $km^2$ inside Iran and a small part within the Turkmenistan territory. Due to the physiographic condition, the mean annual precipitation increases from less than 200 mm near the outlet to more than 500 mm in the high mountains in the most eastern parts. Flash floods and seasonal flows are common hydrologic characteristics of the Atrak River and its tributaries.

**Data**

Although there are many hydroclimatic monitoring stations within the basin, but only a limited number of stations have data with adequate quality and length of observations. In total, 11 hydroclimatic stations with observation length of 30 years or more for the 1975 – 2008 period were selected in this study (Fig. 1). Tab. 1 presents the general information of these stations. Institutionally, the Torshakli, Hotan and Maraveh Tappeh stations are under surveillance of the Surface Water Bureau of the Golestan Regional Water Company. Other stations are administered by the Surface Water Bureau of the North Khorasan Regional Water Company. Both companies are affiliated to the Ministry of Energy of Iran. As shown in Fig. 1, the stations are not fairly well distributed. In fact, the density of stations are higher near the center of the basin where population density is higher. It should be noted that even in these limited number of stations, data series contained missing values and outliers which were checked and preprocessed before further statistical analyses. The outliers were only found for the maximum discharge time- series at the hydrometric stations. Cross-checking of the historic flood events within the basin with the maximum discharge time-series indicated that these outliers are real. Except for the maximum discharge time-series, missing values were estimated using correlation methods. Since no statistically significant correlation was found between the maximum discharge time-series of the hydrometric stations, it was decided to leave these gaps intact and only apply the non-parametric test of Mann-Kendall on these time-series. The Mann-Kendall test can be used for data series with missing values (Molnar & Ramirez, 2001). Such missing values, however, were less than 10% of the total for an individual time-series in the most extreme case.

Trends in discharge, precipitation, temperature, and potential evaporation variables were analyzed. First, the long term observations of discharge variable (annual mean) at 8 hydrometric stations were assessed to find out whether there is any indication of changes in streamflows of the Atrak River basin. Second, the long term records of meteorological variables including annual precipitation at all stations, and annual temperature variables (mean, minimum and maximum), annual pan evaporation and potential evaporations at 5 pan-evaporimeter stations (Torshakli, Aghmazar, Barbarghale, Resalat, and Seyekab) were examined to find out indications of climate changes. Finally, the relationship between trends in streamflow and meteorological variables were investigated and discussed.

**Table 1.** Geographic characteristics of the hydro climatological stations

| Station | U.T.M | | Height (masl) | Start date | Data length (Years) | Station type |
|---|---|---|---|---|---|---|
| | X | Y | | | | |
| Baba Aman | 538844 | 4147632 | 1010 | 1972 | 35 | Raingauge and hydrometry |
| Aghmazar | 492020 | 4172381 | 560 | 1969 | 36 | Pan evaporimeter and hydrometry |
| Darkesh | 477596 | 4144120 | 1040 | 1972 | 36 | Raingauge and hydrometry |
| Shirabad | 492926 | 4145588 | 850 | 1965 | 35 | Raingauge and hydrometry |
| Ghatlish | 526992 | 4185123 | 960 | 1972 | 36 | Raingauge and hydrometry |
| Darband | 498387 | 4162034 | 680 | 1972 | 35 | Raingauge and hydrometry |
| Seyekab | 582737 | 4140949 | 1138 | 1975 | 33 | Pan evaporimeter |
| Barbarghale | 526000 | 4147000 | 1123 | 1965 | 37 | Pan evaporimeter |
| Resalat | 475000 | 4151000 | 842 | 1975 | 34 | Pan evaporimeter |
| Maraveh Tappeh | 408001 | 4196075 | 191 | 1955 | 33 | Raingauge and hydrometry |
| Hotan | 369696 | 4201320 | 77 | 1974 | 33 | Raingauge and hydrometry |
| Torshakli | 307956 | 4172979 | 25 | 1970 | 29 | Pan evaporimeter and hydrometry |

### Trend analysis method

Trend analysis was conducted using the nonparametric Mann-Kendall test which is usually used for hydroclimatic data analysis (Molnar & Ramirez, 2001). The test is based on the correlation between the ranks of time-series and their time order (Hamed, 2008). This method is especially suitable for non-normally distributed data, censored data, data containing outliers, and nonlinear trends (Molnar & Ramirez, 2001). According to Mann (1945), the null hypothesis $H_0$ states that the deseasonalized data ($x_1, x_2, \ldots, x_n$) are a sample of $n$ independent and identically distributed random variables (Yu *et al.*, 1993). The alternative hypothesis $H_1$ of a two-sided test is that the distribution of $x_i$ and $x_j$ are not identical for all $i, j \leq n$ with $i \neq j$.

## 3. Results and discussion

Prior to presenting and discussing the detailed results of statistical analysis of the Mann-Kendall test for each station separately, the results of explanatory analysis for the basin wide average values of the annual mean discharge, annual precipitation, annual mean temperature, annual pan evaporation, and annual potential evapotranspiration are shown in Fig. 2 to 6. As can be seen in Fig. 2, the rate of decline in the observed value of annual mean discharge in the most downstream studied station within the basin namely the Torshakli station, is very remarkable. In fact, the recorded values of discharge in this station have been used as a representative for the whole basin. In general, average value of annual discharge of the basin has decreased more than 50% from the decade 1975 -1984 to the decade 1995–2004 (Fig. 2). This indicates a very large change in the hydrologic regime of the basin. This remarkable decrease in discharge of the Atrak River basin, which is located in an arid and semi-arid region, requires a great deal of attention from water resources management point of view.

Usually, variation in the precipitation is considered a main cause of variation in streamflow. Therefore, the basin-wide average value of precipitation was first calculated through arithmetic averaging of precipitation at 11 rain-gauge stations across the basin. Then, its annual and decadal variations was depicted and presented in Fig. 3.

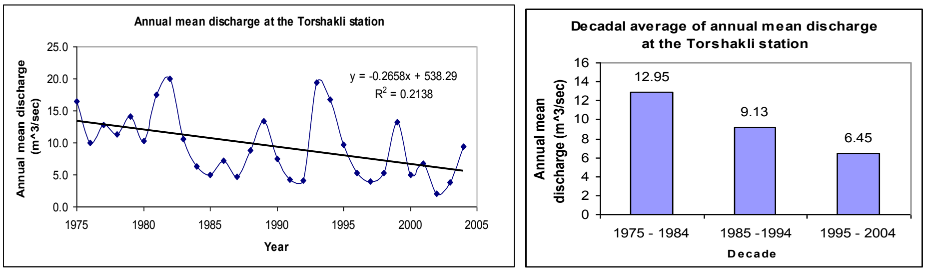


**Figure 2.** Annual and decadal variations of mean discharge of the Atrak River basin recorded at the Hotan hydrometry station

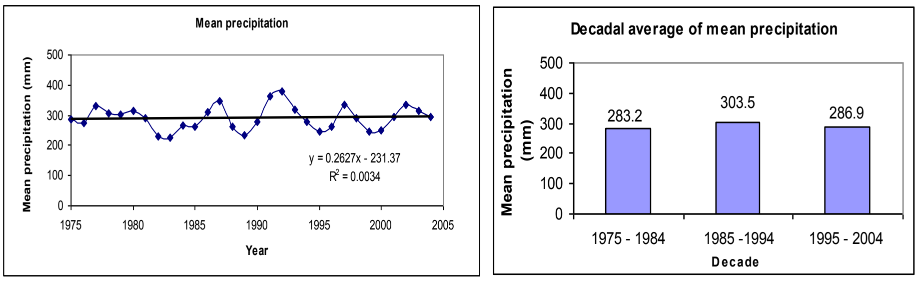


**Figure 3.** Annual and decadal variations of mean precipitation of the Atrak River basin

Interestingly and/or unexpectedly, despite inter-annual variations, no clear trends in the average value of precipitation is detectable during the period 1975 through 2004. Decadal comparison of mean precipitation shows that in the decade 1985–1994 precipitation is slightly higher than the decades before and after. This is mainly due to the wet period of 1991-1993. According to this finding, the significant downward trend of the mean discharge cannot be explained with variations in precipitation. Therefore, other components of the hydrologic cycle might be responsible for changes in the mean discharge. Basically, the water balance of a basin is expressed as the following equation:

(5) $$\Delta S = P - Q - ET$$

Where P is precipitation (L), Q is runoff depth (L), ET is the actual evapotranspiration loss (L), and ΔS is changes in storage of basin (L). Usually for a long term water balance study, the storage change is considered negligible and water balance equation is simplified as:

(6) $$Q = P - ET$$

According to the equation 6, if the observed decreasing trend in discharge cannot be attributed to precipitation, then it should be related to water loss via evapotranspiration. Evapotranspiration, dissimilar to the other components of the water balance, is not routinely measured directly. However, potential evaporation rate is measured through pan-evaporimeters and is multiplied by a coefficient to represent the potential evapotranspiration (ETo). Furthermore, evaporation value can also be estimated using empirical or physical relationships. There are a few methods with different levels of complexity and data requirement to calculate potential evapotranspiration. In this research the Hargreaves and Samani method was used to calculate ETo. (Hargreaves & Samani, 1985).

(7)
$$ETo = 0.0023 Ra(T + 17.8)\sqrt{DTR}$$
$$DTR = T\max - T\min$$
$$Ra = 37.6 Dr(Ws.\sin\phi.\sin\delta + \cos\phi.\cos\delta.\sin Ws)$$
$$Ws = \arccos(-\tan\phi.\tan\delta)$$
$$Dr = 1 + 0.033\cos(0.0172 J)$$
$$\delta = 0.409\sin(0.0172 J - 1.39)$$
$$J = \mathrm{int}(30.5 M - 14.6)$$

Where *Ra* is extraterrestrial solar radiation ($MJm^{-2}d^{-1}$), *Dr* is relative distance of Earth to Sun in astronomical unit (AU), $\delta$ is solar declination in radians, $\Phi$ is latitude in radians, *Ws* is hour angle in radians, *M* is the month number (1 to 12), and *J* is julian day number (1 to 365).

In the Hargreaves and Samani method and most of the other methods, temperature is used as the main factor influencing the evapotranspiration rate. Therefore, in this study changes in the annual minimum, mean and maximum temperatures as well as diurnal temperature range (DTR) were investigated as indicators of the evaporative power of atmosphere. To this end, the annual and decadal variations of the basin-wide average value of mean temperature across the Atrak River basin have been presented in Figure 4.

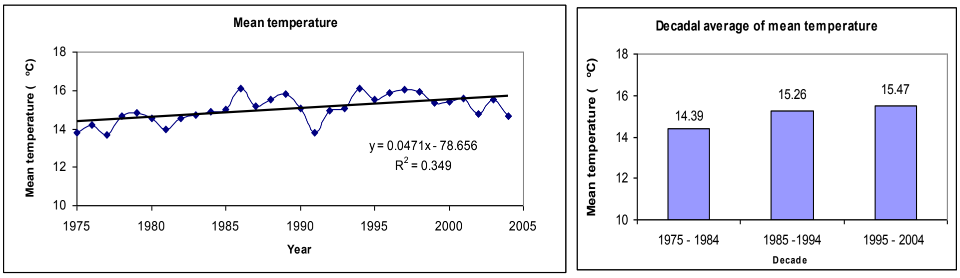


**Figure 4.** Annual and decadal variations of mean temperature across the Atrak River basin

As is seen in Figure 4, mean temperature of the basin shows a very significant positive trend. Whereas, its average value has increased from 14.39 °C in the decade 1975-1984 to 15.47°C in the decade 1995-2004. In comparison with the mean global increase of about 0.6±0.2°C per century (McCarthy *et al.,* 2001), the value of 0.37°C change per decade is very large for the Atrak River basin. In other words, the evaporative power of the basin has been intensified significantly. To further justify this finding, variations in average value of pan evaporation measured within the class A pan-evaporimeters at 5 stations as well as estimated potential evapotranspiration have been displayed in Fig. 5 & 6. As is seen in Fig. 5, the average value of pan evaporation across the basin has increased very significantly. In fact, the potential evaporation rate of the area has augmented about 200 mm during 30 years.

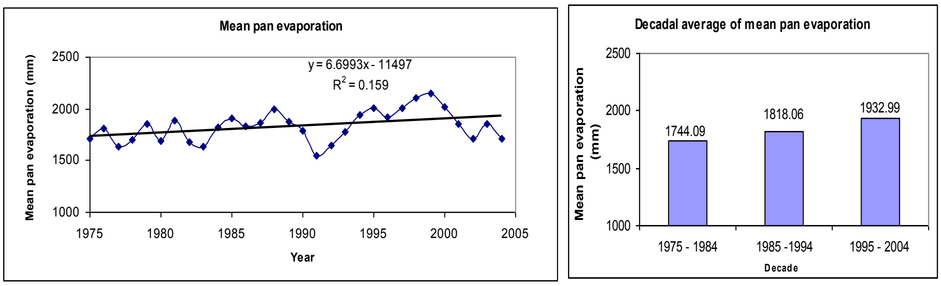


**Figure 5**. Annual and decadal variations of pan evaporation across the Atrak River basin

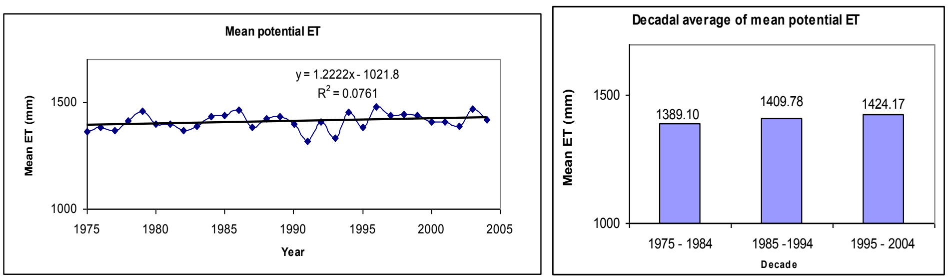


**Figure 6.** Annual and decadal variations of potential evapotranspiration across the Atrak River basin

As is shown in Fig. 6, the average value of potential evapotranspiration indicates an upward trend too. However, the magnitude of increment is not as much as pan evaporation.

Although the decreasing trends of mean discharge of the basin can be logically attributed to the increasing trend of temperature and evaporative power of the atmosphere, it should not be neglected that there are multiple other reasons such as land use and land cover changes and artificial regulatory constructions within the basin which might explain the changes in the hydrologic behavior of a watershed.

Given that the explanatory analyses have shown the general trends of average values of variables of interest across the whole Atrak River basin, the detailed results of Mann-Kendall statistical test per station and variable are presented in Fig. 7-9 to show the spatial distribution of trends and prove the detected trends statistically. In these figures, trends significant at 95% confidence level are shown with large dots and non-significant trends at the 95% level with small dots. Increasing trends have been presented with black dots and decreasing trends with white dots.

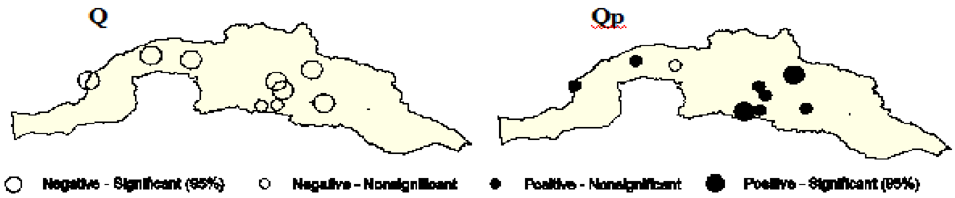


**Figure 7.** Spatial distribution of trend direction of annual mean discharge and annual maximum discharge

Figure 7 indicates that all 8 hydrometric stations present downward trends in annual mean discharge (Q) which is significant for only 6 stations. This indicates that shortage of water resources in the Atrak River basin, where climate is arid and semi-arid, will be a serious problem, particularly during the drought events which are frequent phenomena in the area. Since more than 77% of the Atrak River basin is covered with mountains, inhabitants of the area are mainly dependent on surface water resources. Therefore, downward trend of streamflow makes the situation of the area critical from water resources management point of view. Despite significant decreasing trend in annual mean discharge, magnitude of floods is increasing. This can be clearly noticed from the almost consistent upward trends of annual maximum discharges (Qp) except for the Maraveh Tappeh station. However, the upward trends are significant at 95% confidence level only at the Ghatlish and Darkesh stations. Therefore, not only the shortage of water resources is a critical issue but also the flood hazards will be another serious issue in the inundation prone regions of the Atrak River basin. Due to the physiographic conditions of the basin, the most economically productive lands of the study area are distributed alongside the stream networks which provide irrigation water. Location of these lands makes them the most flood prone areas. The observed increasing trends in annual maximum discharge and decreasing trend in annual mean discharge are in agreement with the IPCC reports and predictions (McCarthy *et al.,* 2001; Parry *et al.,* 2007).

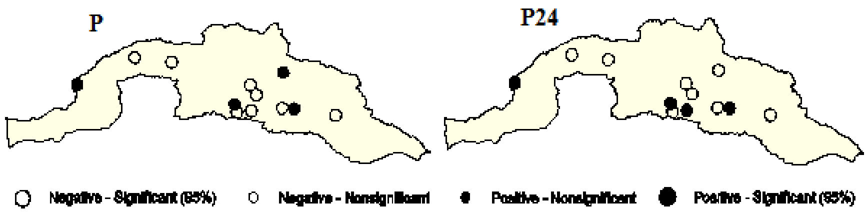


**Figure 8.** Spatial distribution of trend direction of annual precipitation and maximum daily precipitation.

Time-series of precipitation variables show almost no significant trends at the 95% confidence level (Fig. 8). As seen in Figure 8, none of stations show a significant decreasing or increasing trend for annual precipitation and maximum daily precipitation.

Generally speaking, the decreasing trends in the mean discharge is in agreement with the Intergovernmental Climate Change (IPCC) report in 2007 which has predicted about 10 to 30 percent decrease in the annual average runoff over some dry regions at mid-latitudes and in dry tropics by mid-century (Parry *et al.,* 2007). However, this decreasing mean discharge cannot be explained by variations in the annual precipitation in the study area.

If the precipitation regime of the area has not undergone any changes, questions arise about other possible causes of the changes in the hydrological regime. Based on the previous investigations on climate change in regional or global scales, there is a common sense that the planet Earth has been experiencing warming trends (Lettenmaier *et al.*, 1994; Burn & Elnur, 2002; Qader, 2001; Kundzewicz 2008). Warming of climate consequently will speed up the evaporative power of the atmosphere (Ohmura & Wild, 2002). Hence, in the following section any indication of warming trend of the basin's climate and its influences on potential evapotranspiration rate is presented.

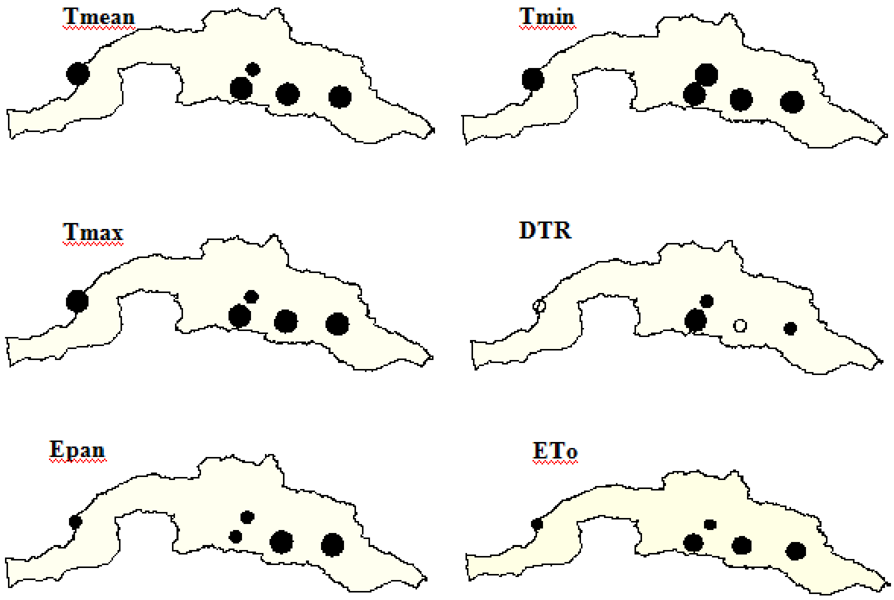


**Figure 9.** Spatial distribution of trend direction of annual mean temperature (Tmean), maximum temperature (Tmax), minimum temperature (Tmin), diurnal temperature range (DTR), pan evaporation (Epan) and potential evapotranspiration (ETo).

As is seen in Fig. 9, all temperature indices show upward trends. Almost all temperature indices in almost all stations indicate significant trends at the 95% confidence level. The observed trends of most of the indices are even significant at the 99% confidence level (not shown in the article). Higher trends were observed for nighttime temperatures (Tmin). Since the daytime temperature (Tmax) do also show significant increasing trend, the diurnal temperature range (DTR) time-series do not indicate consistent significant upward trend across the stations.

Trend analysis of the observed pan evaporation (Epan) time-series indicates uniform increasing trends across all stations which is significant at the 95% confidence level and more at two of the stations. The long term time-series of the calculated potential evapotranspiration (ETo) indicated that there is almost a consistent trend within the Atrak River basin which is significant at the 95% confidence level at three stations of Seyekab, Barbarghale and Resalat. In the Torshakli station, the observed trend is downward but non-significant. Considering the almost consistent upward trends of Epan and ETo, it can be concluded that the observed downward trend of annual discharge can be explained by warming of climate within the Atrak River basin. Therefore, water resources management authorities of the area are suggested to consider the likely impacts of warming trends in their management policies and strategies which currently rely on constructions of mid-size dams and open reservoirs.

## 4. Conclusion

This work provides a clear picture of the streamflow and climate changes across the Atrak River basin, in northeast of Iran. Major findings of this investigation are:

(i) All annual mean discharge time-series observed at the 8 hydrometric stations present homogenous downward trends. Except for two stations of Darkesh and Shirabad, at the other 6 stations the observed trends are significant at 95 percent confidence level.

(ii) Despite decreasing trends in annual mean discharge, almost homogeneous increasing trends have been observed in the annual maximum discharge time-series.

(iii) Although it is assumed that precipitation changes play a major role in streamflow changes, no clear and homogenous increasing or decreasing trend has been found in the long term time-series of the recorded precipitation data across the basin.

(iv) Contrary to the precipitation trends, homogenous increasing trends have been observed in the long term time-series of the temperature and evaporation variables. This indicates an increase in the evaporative power of atmosphere which might be a reason for decreasing trends of annual mean streamflows.

(v) Although observed decreasing trends in streamflows within the Atrak River basin is in the range of its projected value according to the IPCC reports, but the observed increasing trends in mean temperature is much higher than the global mean value.

## Acknowledgment

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### References

Abdul Aziz, O.I., and Burn, D.H. 2006 Trends and variability in the hydrological regime of the Mackenzie River Basin. Journal of Hydrology. 319: 282-294.

Birsan, M.V., Molnar, P., Burlando, P., and Pfaundler, M. 2005. Streamflow trends in Switzerland. Journal of Hydrology. 314: 312-329.

Burn, H.B., and Elnur, M.A. 2002. Detection of hydrologic trends and variability. Journal of Hydrology. 255:107-122.

Douglas, E.M., Vogel, R.M., and Kroll, C.N. 2000. Trends in floods and low flows in the United States: impact of spatial correlation. Journal of Hydrology. 240: 90-115.

Hamed, K.H. 2008. Trend detection in hydrologic data: The Mann-Kendall trend test under scaling hypothesis. Journal of Hydrology. 349: 350-363.

Han, D. 2007. Seasonal rainfall and flow trends within three catchments in south-west England. Flood Risk Management in Europe (eds. Begum, S. *et al.*). pp:275-292. Springer.

Hargreaves, G.H., and Samani, Z.A. 1985. Reference crop evapotranspiration from temperature. Applied Engineering Agriculture. 1: 96-99.

Hodaei, S. 2008. Critical focal points within the Atrak River basin in the North Khorasan province. North Khorasan Natural Resources Administration, Bojnord, Iran.

Kundzewicz, Z.W. 2008. Climate change impacts on the hydrological cycle. Ecohydrology and Hydrobiology. 8 (2-4):195–203.

Lettenmaier, D.P., Wood, E.F., and Wallis, J.R. 1994. Hydro-climatological trends in the Continental United States, 1948-88. Journal of Climate. 7: 586-607.

Lins, H.F., and Slack, J.R. 1999. Stream flow trends in the United States. Geophysical Research Letter. 26(2): 227–230.

Mann, H.B. 1945. Nonparametric tests against trend. Econometrica 13: 245-259.

Mc Carthy, J.J., Canziani, O.F., Leary, N.A., Dokken, D.J., and White, K.S. (eds.). 2001. IPCC. Climate Change 2001 – Impacts, Adaptation and Vulnerability Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambrifge University Press. Cambridge. 1032 pp.

Milly, P.C.D., Dunne, K.A., and Vecchia, A.V. 2005 Global pattern of trends in stream flow and water availability in a changing climate. Nature. 438: 347-350.

Molnar, P., and Ramirez, J.A. 2001. Recent trends in precipitation and stream flow in the Rio Puerco basin. Journal of Climate. 14: 2317-2328.

Ohmura, A., and Wild, M. 2002. Is the hydrologic cycle accelerating? Science. 298:1345–1346.

Parry, M.L., Canziani, O.F., Palutikof, J.P., and Co-authors. 2007. Technical Summary. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, (eds.), Cambridge University Press, Cambridge, UK, 23-78

Qader, M.M. 2002. Global warming and changes in the probability of occurrences of floods in Bangladesh and implications. Global Environmental Change. 12: 127-138.

Robson, A.J., Jones, T.K., Reed, D.W., and Bayliss A. 1998. A study of national trend and variation in UK floods. International Journal of Climatology. 18: 165-182.

Sheikh, V., and Bahremand, A.R. 2009. Investigation on hydrological trends of Atrak River basin. Research report. Research Vice-Presidency of Gorgan University of Agricultural Sciences and Natural Resources, Gorgan, Iran.

Sheikh, V., and Bahremand, A.R. 2011. Trends in precipitation and streamflow in the semi-arid region of Atrak River Basin, North Khorasan, Iran. Desert. 16: 49-60.

Yue, S., and Pilon, P. 2004. A comparison of the power of the t test, Mann-Kendall and bootstrap tests for trend detection. Hydrology Science Journal. 49(1):21-37.

Zhang, X., Harvey, K.D., Hogg, W.D., and Yuzyk, T.R. 2001. Trends in Canadian stream flow. Water Resources Research. 37(4): 987-998.