THE EFFECTS OF CLIMATE CHANGE ON THE FLOW THROUGH KHORASSAN WATERCOURSES

EFFETS DES CHANGEMENTS CLIMATIQUES SUR LE DEBIT DES COURS D'EAU DE KHORASSAN

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ABSTRACT

The mean temperature over Iran is likely to increase substantially in the future. As a result of temperature increase, the demand for water will increase too. It is expected that snow precipitation will be changed toward rain and the area of snow coverage in mountainous regions will be less than last decades. Shorter time of snow cover will change the season of peak runoff from summer to spring or from spring to winter. As a result of change in precipitation type and precipitation season, a change in runoff and the flow in river is anticipated. The increase in evaporation consequent to rise in temparature will decrease the flow and intensity of runoff. A survey on historical precipitation data from 600 rainfall stations of IRAN shows a shift of some wet stations to dry stations. According to some investigations, the frequency of dry years in Iran has been increased and drought periods have become longer. In the west part of Iran, runoff is a result of snow melting from high level mountains, so by a decrease of snow coverage the runoff will decrease. Higher evaporation because of increase in temperature will reduce the amount of flow in rivers. The frequency of floods will also be changed and more severe floods may be expected than before. More showers instead of normal rains causes the soil hardness and so infiltration of water into the soil and aquifers will be decreased too. Prediction models (mostly GCM)using climate parameters with different scenarios were used to predict climate change in Khorassan. The result shows that significant warming trends are evident over the northern regions. Significant linear trend rates vary between 0.70^{0}C to 1.3^{0}C per decade. According to a recent investigation in Khorassan area, drought is a continuous phenomena in this region and temperature increase between 1.5^o to 6^o C is certain for most cities of Khorassan in 2050.

Key words: *Climate change, global warming, water resources, Iran, longer droughts.*

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RESUME ET CONCLUSION

Le climat est un facteur important dans l'étude des ressources en eau et la disponibilité future de l'eau. Pour inclure les effets du changement climatique dans les programmes d'eau, il est nécessaire d'éviter les risques et la vulnérabilité de l'eau. En utilisant les modèles sophistiqués, certains centres météorologiques mondiaux ont mentionné l'augmentation de 2 à 4 Co dans la moyenne de la température de la planète dans l'avenir proche. L'Iran, qui se trouve dans une zone semi-sèche et sèche du monde, sera également affectée par l'augmentation de la température de 2 à 4 degrés centigrades. Le résultat de nombreux documents montre les tendances négatives dans la plupart des régions de l'Iran. Il y a aussi des tendances positives dans certaines régions du pays. Les tendances positives et négatives sont le signe du changement climatique en Iran. Selon les recherches effectuées en Iran par les rapports du GIEC utilisant les modèles MCG, la température moyenne de l'Iran va augmenter de manière considérable. Avec l'augmentation de la température, la demande en eau augmentera également. Les précipitations de neige seront changées en pluie, et la couverture de neige sur les régions montagneuses sera réduite par rapport aux dernières décennies. Une réduction du temps de la couverture de neige va changer la saison pointe de l'écoulement de l'été au printemps ou du printemps à l'hiver. En raison du changement du type de précipitation et de la saison des précipitations, un changement est attendu dans les eaux de ruissellement et le débit de la rivière. L'augmentation de l'évaporation diminuera le débit et l'intensité des eaux de ruissellement. Une enquête menée sur les données historiques des précipitations à partir de 600 stations pluviométriques de l'Iran montre un déplacement de certaines stations humides aux stations sèches. Selon certaines enquêtes, la fréquence des années de sécheresse en Iran a augmenté et les périodes de sécheresse sont devenues plus longues. Dans l'ouest de l'Iran, le ruissellement est le résultat de la fonte des neiges des montagnes, donc avec une diminution de la couverture de neige, le ruissellement réduira. Plus d'évaporation à cause de l'augmentation de la température permettra de réduire la quantité de débit des rivières. Les inondations plus graves que dans le passé sont également attendues.

Mots clés : *Changement climatique, réchauffement de la planète, ressource en eau, Iran, sécheresses longues.*

1. INTRODUCTION

In 2007, the International Panel on Climate Change released its Fourth Assessment Report (IPCC, 2007) concluding that the release of greenhouse gases (e.g., carbon dioxide, methane, nitrous oxides, etc.) is altering the earth's heat budget and causing climatic changes. These changes include significant alterations of the water cycle and other water-related parameters.

The report states that global temperature has already increased 0.74^{0}C from 1906 to 2005 affecting spatial, and temporal amount and distribution of precipitation, as well as mountain glaciers and snow cover which maintain river flows throughout the year. In general, precipitation has decreased during the last century in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia. In Africa and Asia, the area affected by drought has increased during the last three decades. Mountain glaciers and snow cover have also declined around the world, causing increased run-off and early spring peak discharge in many areas while in dry regions, decline in river flow in spring and summer and a shift in runoff peak season. The increased early season runoff makes a short-term water supplies for downstream water users, but the long-term viability of water and snow-fed lands are the actual problem for irrigation (Kathleen Miller and David Yates, 2005).

In terms of future projections, these trends are expected to continue. Temperatures are expected to rise, causing some areas to become wetter and others drier. In general, annual river flow is expected to decrease in some dry regions in the mid-latitudes and tropics, and many semi-arid regions will suffer a decrease in water resources (e.g., Mediterranean basin, western United States, southern Africa, and northeast Brazil). Reduced rainfall, increased evaporation rates, saltwater intrusion into water systems along coastal areas, and reduced mountain glaciers and snow cover will all affect the availability of quality water supplies. IPCC report (2007) does not speak more about cautionary implementations but insist more on climate change as a fact of scientific investigations and recommends all nations and governments to find a solution by compatibility and reduction of the climate change effects.

Figure 1 shows the spatial distribution of drought severity in the world and Fig. 2 shows Variations of the Earth's surface temperature for the past 140 years (1860 to 2000).

An over view of IPCC 2007 report reveals the following facts about the future climate :

- Global mean surface temperatures have risen by 0.74°C ± 0.18°C when estimated by a linear trend over the last 100 years (1906–2005). The rate of warming over the last 50 years is almost double that over the last 100 years *
- Land regions have warmed at a faster rate than the oceans
- Changes in extremes of temperature are also consistent with warming of the climate.
- Recent warming is strongly evident at all latitudes in SSTs over each of the oceans
- Precipitation has generally increased over land north of 30°N over the period 1900 to 2005 but downward trends dominate the tropics since the 1970s.
- Substantial increases are found in heavy precipitation events
- Droughts have become more common, especially in the tropics and subtropics, since the 1970s.
- Cloud changes are dominated by the El Niño-Southern Oscillation and appear to be opposite over land and ocean
- Changes in the large-scale atmospheric circulation are apparent
- Mid-latitude westerly winds have generally increased in both hemispheres
- Intense tropical cyclone activity has increased since about 1970

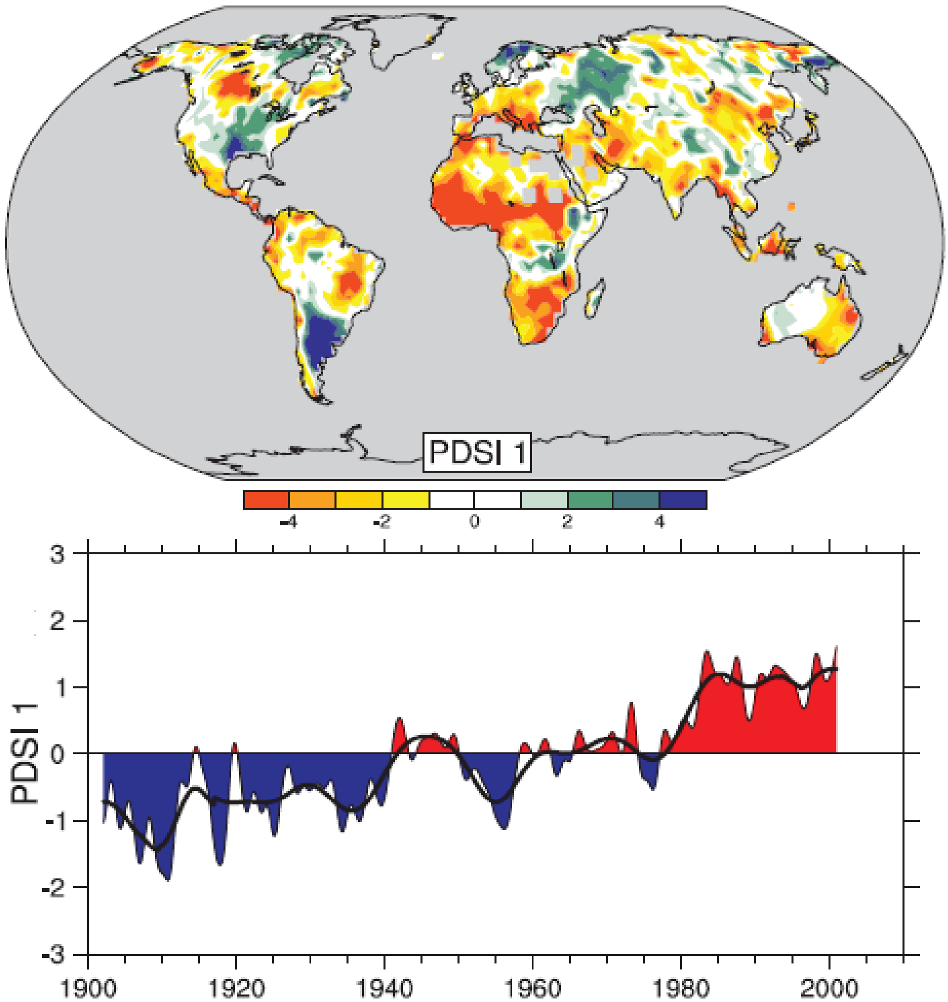

Fig. 1. Spatial pattern of the monthly palmer Drought Severity Index for 1900 to 2002

The most important spatial pattern (top) of the monthly Palmer Drought Severity Index (PDSI) for 1900 to 2002. The PDSI is a prominent index of drought and measures the cumulative deficit (relative to local mean conditions) in surface land moisture by incorporating previous precipitation and estimates of moisture drawn into the atmosphere (based on atmospheric temperatures) into a hydrological accounting system. The lower panel shows how the sign and strength of this pattern has changed since 1900. Red and orange areas are drier (wetter) than average and blue and green areas are wetter (drier) than average when the values shown in the lower plot are positive (nega-tive). The smooth black curve shows decadal variations. The time series approximately corresponds to a trend, and this pattern and its variations account for 67% of the linear trend of PDSI from 1900 to 2002 over the global land area. It therefore features widespread increasing African drought, especially in the Sahel, for instance. Note also the wetter areas, especially in eastern North and South America and northern Eurasia. (IPCC 2007- Volume 3 Drought)

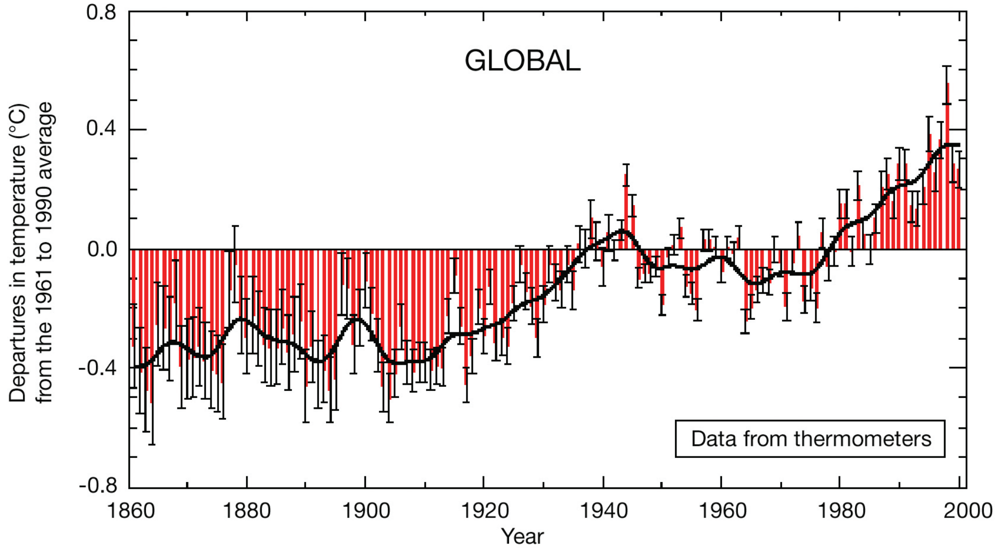

Fig. 2. Variations of the Earth's surface temperature for the past 140 years (1860 to 2000). Source: IPCC 2001, p. 26.

2. CLIMATE CHANGE IN IRAN

According to different climate studies and models used for investigations over Iran, there is a similarity of results in IPCC reports and Iranian climatologists' investigations (IPCC 2007 , Koocheki et al, 2006; Soltani et al., 2001, Kathleen Miller and David Yates, 2005)

Temperature and precipitation

Alizadeh et al.,.(2005), selected climate data from Mashhad synoptic station and 34 other hydro meteorological stations and used regression model to study climate change in Mashhad plain. Two statistical models, Man Kendal and Loten Mayer were used to study the trend of temperature. The results showed an increasing trend in the Mean, Minimum and the Maximum temperatures in most of the stations. The final results of the study showed an increase of 1.8^0 C by 2025 and of 2.35^0 C by 2050.

Kucheki et al., (2006) in another investigation used GISS[2] and GFDL[3] models to predict the future climate change. Investigation showed that with a double CO^2 in the atmosphere, most of the cities (Synoptic stations) in Iran will have an increase of 3.9^0 C to 4.3^0 c in annual mean temperature and also an increase of annual rainfall between zero and 15% (Table 1). Table 2 shows increase in monthly temperature and change of rainfall in comparison to the present period of Tabriz synoptic station.

Babaeyan I, (2008) using MAGIC SCENGEN model over Iran confirms an increase of 1.5^0 to 4.5^0 C in mean temperature in 2005 – 2039 period in comparison to the present data (1976-

2 GISS : Godard Institute for Space Studies
3 GFDL : Geophysical Fluid Dynamic Laboratory

2005). Figure 3 shows increase of temperature with different scenarios and Fig. 4 shows the location of hot days in future (2005-2039).

Soltani A. (2001) used a GFDL model with simulation for two location, Rasht and Ahwaz in Iran and concluded that the increase in temperature of Rasht and Ahwaz would be 4.5^0 C and 4.6^0 C, respectively, during the rice growing season. Rainfall during rice growing season will reduce by 38.8% (102 mm) for Rasht and 68.2% (5.8 mm) for Ahwaz.

Table 1. Effect of doubling CO_2 concentration on mean annual temperature and rainfall in different areas of Iran (predicted by Geophysical Fluid Dynamics Laboratory model [GFDL])

City	Δ temperature (°C)	Δ rainfall (%)
Arak	4.2	14.6
Ardabil	4.2	−0.2
Orumiah	4.3	0.9
Isfahan	4.3	13.9
Ahvaz	4.1	1.9
Ilam	4.2	11.3
Bandar-e Abbas	3.8	9.8
Bushehr	4.4	7.6
Tabriz	4.3	1.1
Tehran	4.2	12.6
Khorram Abad	4.2	13.6
Rasht	4.2	3.4
Zahedan	3.9	14.6
Zanjan	4.2	5.3
Semnan	4.2	14.1
Sanandaj	4.2	8.4
Sari	4.1	11.5
Shahr-e-kord	4.3	14.1
Shiraz	4.1	10.0
Kerman	4.1	14.2
Kermanshah	4.2	13.0
Gorgan	4.1	10.2
Mashhad	4.1	12.8
Hamadan	4.2	11.7
Yasouj	4.2	10.9
Yazd	4.3	13.3

Source : (Kucheki et al., 2006).

Table 2. Effect of doubling CO_2 concentration on mean annual temperature and rainfall using Goddard Institute for Space Studies (GISS) and GFDL models for Tabriz

Month	Δ temperature (°C)			Δ rainfall (mm)		
	Current	GISS	GFDL	Current	GISS	GFDL
1	–2.2	4.2	0.1	22.7	31.4	24.5
2	–0.3	4.2	3.5	22.7	21.6	27.1
3	5.0	8.3	10.4	26.0	16.9	27.0
4	11.4	15.6	15.6	27.7	13.3	31.6
5	16.4	18.1	21.4	30.3	37.3	27.0
6	21.8	25.9	26.4	23.7	30.3	22.7
7	26.1	29.8	30.1	19.3	56.3	13.3
8	25.6	30.4	31.4	20.5	22.5	14.5
9	21.2	27.3	26.8	21.0	39.8	14.9
10	14.1	18.1	17.9	23.6	35.9	26.2
11	7.0	13.9	11.3	31.2	32.7	40.8
12	0.7	5.4	4.0	24.9	34.9	32.4

Source : Climate Research Vol.30 : 247-253 , published 26 April 2006

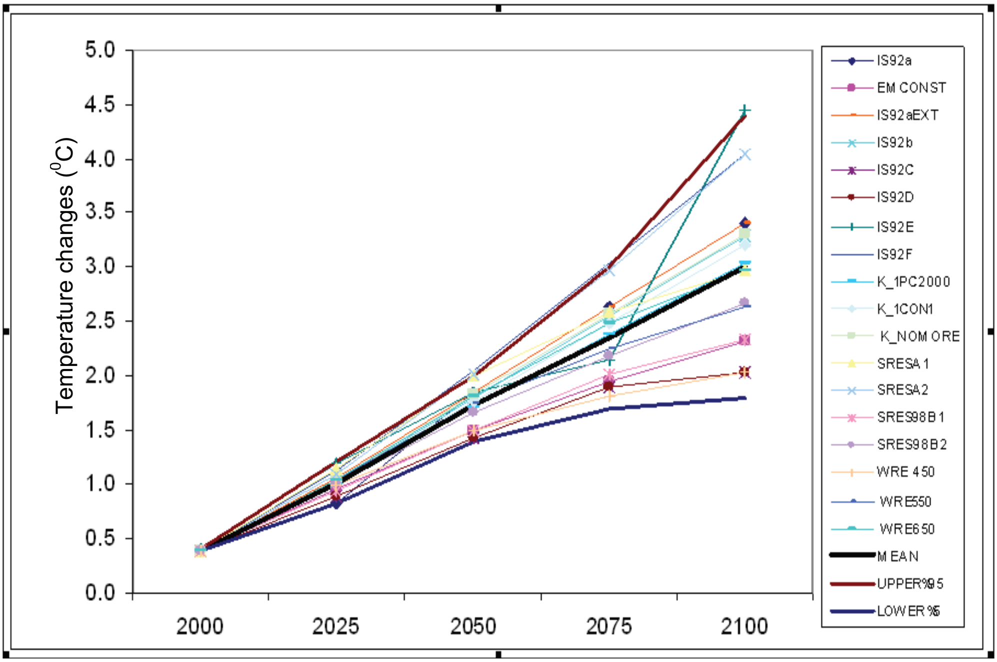

Fig. 3. Mean temperature changes 2000-2100 over IRAN (Babaeyan-2008)

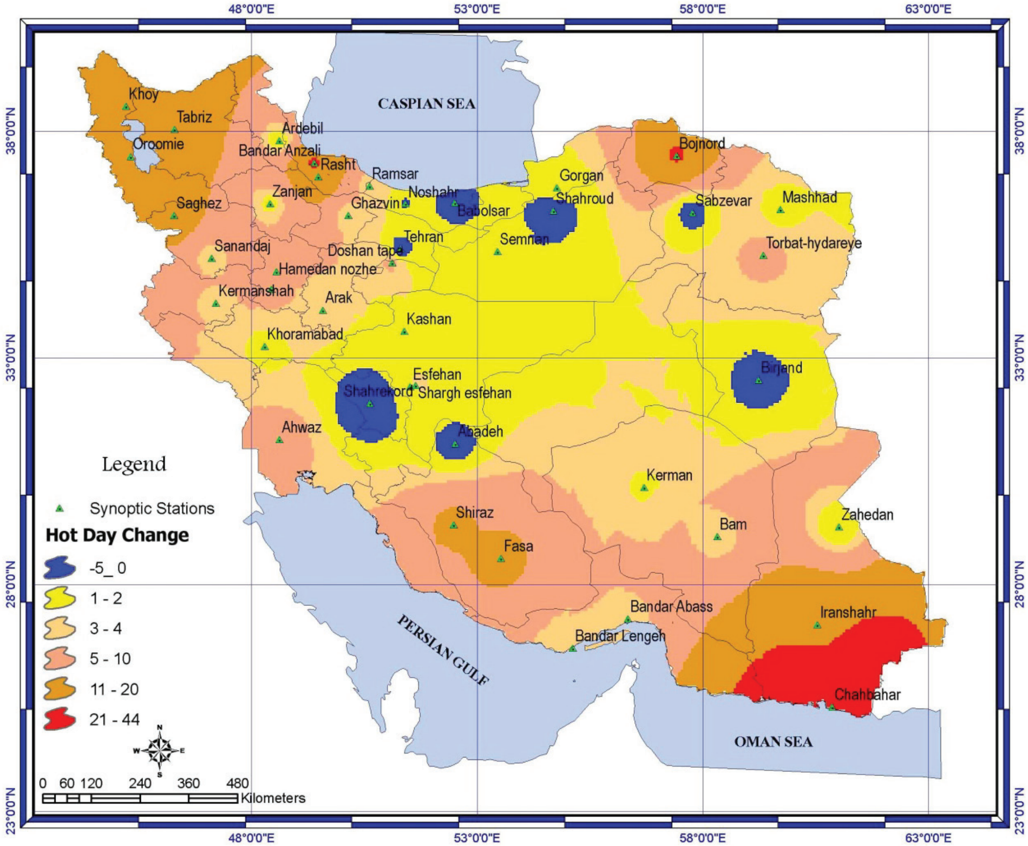

Fig. 4. Hot days change in Iran, 2005-2039 (Babaeyan 2008)

Extremes

Global warming has an effect on the probability and intensity of extreme events. This is true for precipitation as well as temperature, because the amount of water vapor that the air carries is a strong function of temperature. So the frequency of extremely heavy rain and floods increases as global warming increases (Kathleen Miller and David Yates, 2005).

Asgari et al., 2008, has carried out a study on extreme precipitation in Iran. The data he used in analysis was from 27 of Iranian synoptic stations that have reliable data and covering standard normal period 1961-1990. He found all three behaviors of stationary, positive and negative trends over the country. The trends for majority of the indices were positive in regions like Hormozgan, Esfahan, and Tehran, but on the contrary, they were negative for majority of the indices in regions like Azerbaijan and Fars. Former results correspond well with findings of Intergovernmental Panel on Climate Change (IPCC) that expects higher number of occurrences of extreme precipitation events beyond of tropical region. Positive trends for 10 indices in Babolsar and negative trends for 10 indices in Bushehr and Tabriz (7 out of 10 are significant at 0.05 level) indicate complex behaviors of extreme precipitation over the country. Based on the result, they concluded that an abnormal increase in the number of days with high and heavy precipitation was a sign of climate change, but most of the stations in the area of study did not show a significant positive trend of number in heavy rainy days except in Babolsar, a station in Caspian sea shore in the north of Iran. Anzali and Arak stations had the mostly negative trend but Babolsar and Rasht had mostly positive trend.

Water Resources and runoff

Shinohara et al., (2009) have examined a relationship between current and historical shifts in precipitation patterns and concurrent increases in temperature, runoff and other hydrological parameters in a mid – latitude mountainous catchment in central Japan, using data recorded in the period 1965-2001. Based on this model study and historical shift in precipitation and temperature, the probability density functions of runoff were computed. Despite the large increase in temperature in winter and spring, pdf (q) in spring and summer varied during the time studied, mainly because of an increase in snowmelt. The final result of this study was that only winter runoff significantly increased during the period 1965-2001 and that a variation in temperature has more influence on runoff than on precipitation. They believe that potential shifts in the hydrologic balance was responding to climate change in snowy study catchment. The increase of runoff in spring due to temperature increase in relation to climate change will decrease runoff in summer and this effect of global warming on mountain hydrologic regime will be in the timing of runoff.

Research on the global warming effects on hydrology and water resources in Iran has been undertaken on several rivers and lake basins by using historical hydro-meteorological data and runoff models in combination with the global warming scenarios (Climate Change Bureau – 2008). The result of historical runoff data surveys collected at 398 hydrometric stations shows that the Flood Index has changed in 47% of them. In addition, of 600 climatologically stations studied, 68 indicate climate changes during 1990-2000. The long-term runoff model applied to 30 basins shows that the temperature rise increases the runoff volume during winter and decreases it during spring as rising temperature melts snowfall into rain and hastens the time of snow melt. It also indicates that temperature increase affects runoff of basins and decreases the amount of runoff variation of rainfall.

Impact of climate change could have far reaching and unpredictable consequences on water resources in many watersheds (Mohammadnejad et al., 2010). An investigation was carried out by them using a distributed rainfall – runoff process (RRP) in Pishin Basin in Sistan and Baluchestan province in south of IRAN. The calibrated model was utilized to simulate RRP under assessed conditions of climate change till the year 2050 using scenarios from the SRES family generated by IPCC. Results showed that the calibrated model could be useful to properly generate reservoir inflows and could be utilized for runoff prediction under different climate change scenarios. The daily downscaled precipitation in the two rain gauges during December through March was used to predict the Pishin reservoir inflow variation due to climate change. Figure 5 shows the average reservoir inflow, predicted for year 2001 to 2050.

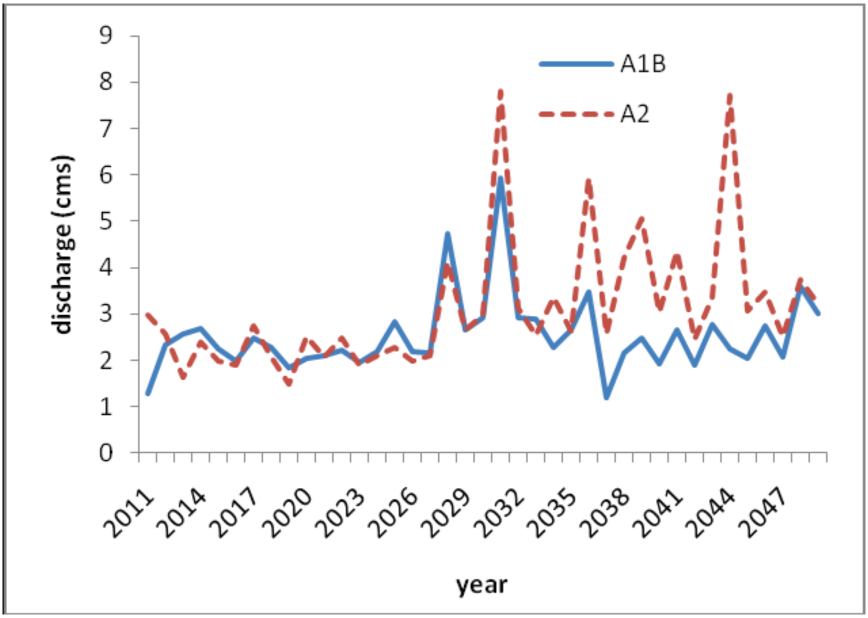

Fig. 5. Average Pishin Reservoir Inflows in the Months of Dec. through March Predicted based on the A1B and A2 Scenarios (Mohamadnejad, et al. 2010).

Climate change and runoff in Khorassan

Khorassan consists of three provinces namely, North Khorassa, Razavi Khorassan and South Khorassan. Large Khorassan area (three provinces) is approximately 314000 km^2. In this paper we discus about Khorassan in general (Fig. 6).

A recent investigation on Khorassan climate change was carried out by Shahabfar et al., (2010), in Climatological Research Institute (CRI) in Mashhad (Figs. 6 & 7) using meteorological data of 17 climatological stations in Large Khorassan. Based on an updated temperature and precipitation data set consisting of monthly averages of the daily mean, daily maximum (day-time) and daily precipitation and annual numbers of freezing days, a general decrease was detected in this climatological parameter series over Mashhad city at the Khorasan Province for period of 1965-2002.

1) Mean temperatures. Year-to-year variations in annual mean temperatures series of Khorasan Province are generally characterized by Kendal coefficient. Significant warming trends from M-K test have shown up particularly at the highly urbanized stations of the northern regions. The significant warming trend rates from the least-squares linear regression vary between 0.51^{0}C to 1.1^{0}C. Most of the spring mean temperature series show an increasing trend. Summer mean temperature series are mostly characterized by a statistically significant Kendall coefficient. Summer mean temperature series have shown a slight warming at many stations over the northern part of Khorasan Province, where as the rest of the province has experienced a general cooling. Autumn mean temperatures have significantly increased at all the three stations.

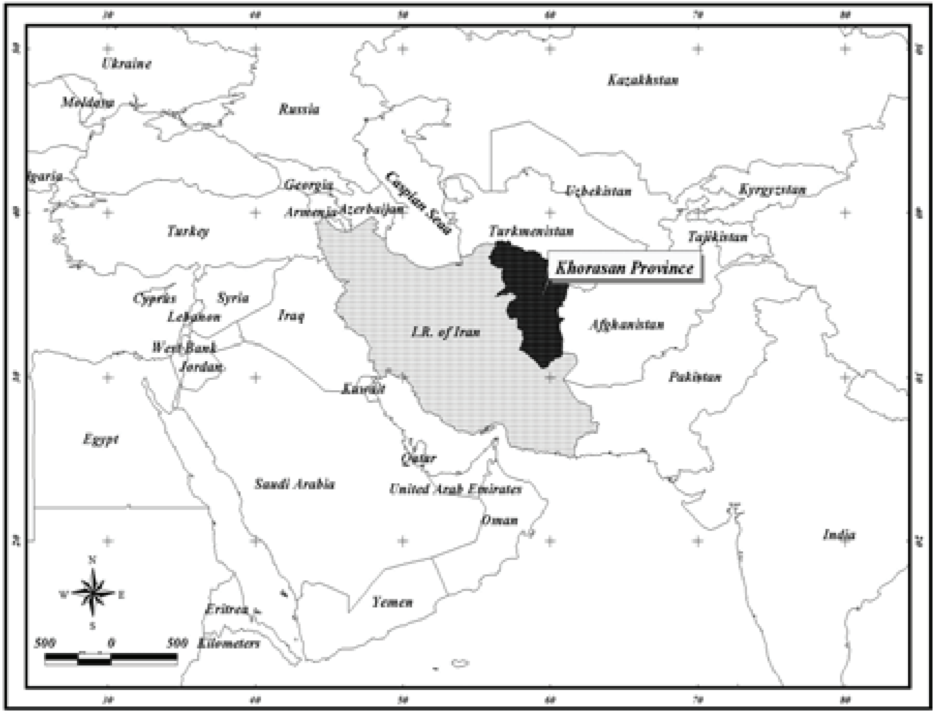

Fig. 6. The geographical location of Khorasan province in the Middle – East (Shahabfar et al-2010)

2) Significant warming trends are evident over the northern regions. Significant linear trend rates vary between 0.700C to 1.30C per decade.

3) Maximum temperature series. The observed low-frequency fluctuations in annual maximum temperature series of Khorasan Province are mostly associated with a significant Kendall Coefficient. A weak increasing trend shows up over the northern regions, and a decreasing trend is generally observed in the inner parts. Year-to-year variability of spring maximum temperatures is mostly characterized by a significant positive serial correlation coefficient. Spring maximum temperature series have indicated an increase at many stations except those in the northern regions. Significant Kendall coefficients at all the stations are a statistical indication of the observed low-frequency fluctuations in summer maximum temperature series. Summer maximum temperatures have increased at many stations and decreased at some stations. Warming trends are significant at four stations. Autumn maximum temperatures have increased over the study region.

4) Minimum temperature series. Year-to-year variations of annual minimum temperatures indicate mostly a significant serial dependence. Most of the rapidly urbanizing and already urbanized stations of Khorasan Province have experienced a night-time warming during the study period, and the warming trends at five stations are significant. The range of significant night-time warming rates is 1.84^{0}C to 0.25^{0}C per decade.

Year-to-Year variations of most spring minimum temperatures have shown a warming trend at majority of the Khorasan Province stations, three of which are significant. The significant night-time warming trends dominate mainly in the highly urbanized or rapidly urbanizing cities of Khorasan province, and significant warming rates lie within the range of 1.56^{0}C to 0.41^{0}C per decade.

Inter annual variations of summer minimum temperatures series at the all of stations are characterized by a significant Kendall coefficient. As in spring, the summer temperatures have increased at the majority of the stations, most of which are located in the already urbanized or rapidly urbanizing cities. Warming trends are significant at five stations. The significant night-time warming rates are in the range of 0.07^{0}C to 1.9^{0}C per decade.

Autumn minimum temperatures series have shown a significant warming trend at four stations, many of which are located in the northern regions of the province. The range of significant warming rates is 0.60^{0}C to 2.8^{0}C per decade.

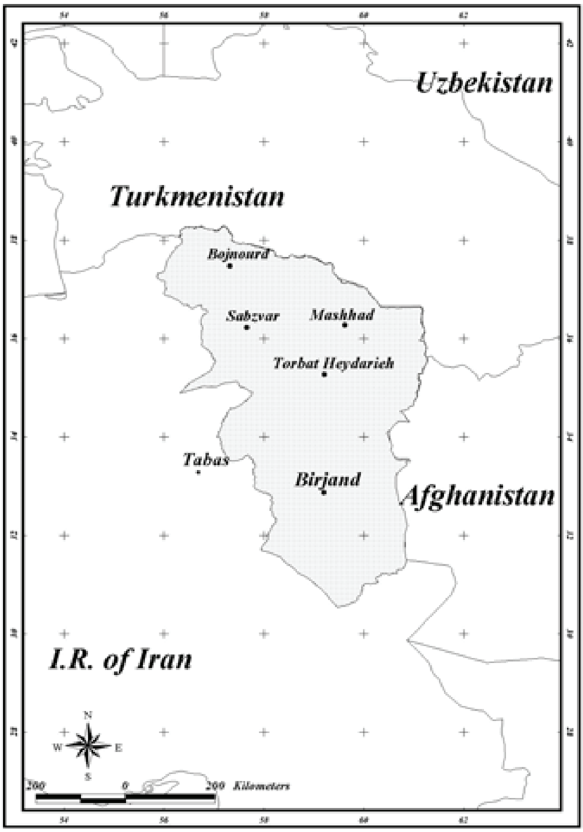

Fig. 7. Spatial distributions of the locations of the synoptic stations in Khorasan province (Shahabfar et al.,2010)

5) Precipitation series. Year-to-year variations in annual precipitation series of Khorasan Province are generally characterized by Kendall coefficient. Significant decreasing trends from

M-K test have shown up particularly at the highly urbanized stations of the northern regions. The significant decreasing trend rates from the least-squares linear regression vary between -2.22 mm to 0.694 mm per decade.

Most spring precipitation series show a decreasing trend. Summer precipitation series are mostly characterized by a statistically significant Kendall coefficient. Summer precipitation series have shown a slight drying at many stations over the northern part of Khorasan Province. Autumn precipitations have significantly decreased at four stations. Significant drying trends are evident over the northern regions. Significant linear trend rates vary between -3.13 mm to 1.24 mm per decade.

6) Overall assessment. According to this research, summer minimum temperatures have generally increased at a larger rate than the spring and autumn minimum temperatures. On the other hand, night-time warming rates of spring and summer are generally stronger than those that exist in spring and summer daytime temperatures. Considering the significant increasing trends in annual, spring and summer temperatures, it is seen that night-time warming rates are stronger in the northern regions, which are characterized by the Khorasan province macroclimate type: a very hot and dry summer, a relatively hot, dry and late spring and early autumn and a moderate winter. It is very likely that significant and very rapid night-time warming trends over much of the province can be related to the widespread, rapid and increased urbanization in Khorasan province, in addition to long-term and global effects of the human-induced climate change on air temperatures.

Abbasi et al., (2010) have also investigated the effect of Climate Change during 2010-2039 on The South Khorassan By using the Min & Max temperature, precipitation and radiation, in a General Circulation Model (GCM) under A1 Senario , the analysis of downscaled meteorological parameters were carried out by Lars-WG model over six meteorological stations of South Khorassan. The result shows that during 2010 – 2039 annual precipitation will increase by 4 percent. Annual mean temperature are projected to be increased in comparison to their normal values by 0.3^0 C with maximum of dry days in northern stations including Boshruyeh, Ferdous and Ghayen but it will decrease in the southern stations of Birjand, Khore and Nehbandan.

The same authors in another investigation (Abbasi et al., 2010b) have investigated the climate change over Iran using MAGICC-SCENGEN Model and found reduced precipitation in most part of IRAN while in some provinces such as Mazandaran, Golestan, North khorasan, North of khorasan Razavi, Tehran, parts of Gillan, Ghazvin and Markazi; the precipitation will increase. The largest increase in precipitation will be in north east and east of Khorasan Razavi province. The results of other scenarios and model are a little different from this model.

The work of Babaeyan et al., (2008) presented in the 4th regional conference on climate change in Tehran, has predicted a significant change of temperature in Large Khorassan. According to their prediction, increasing temperature between 1.5^0 to 6^0 C is probable in Khorassan region (Figs. 8 and 9).

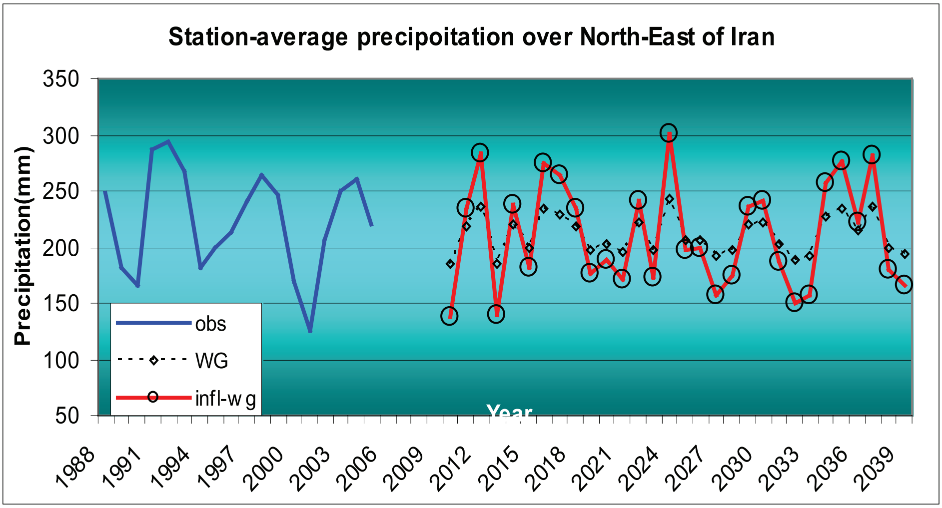

Fig. 8. Predicted precipitation over north east of Iran (Babaeyan et al. 2008): Mean precipitation will decrease by 5.9%.

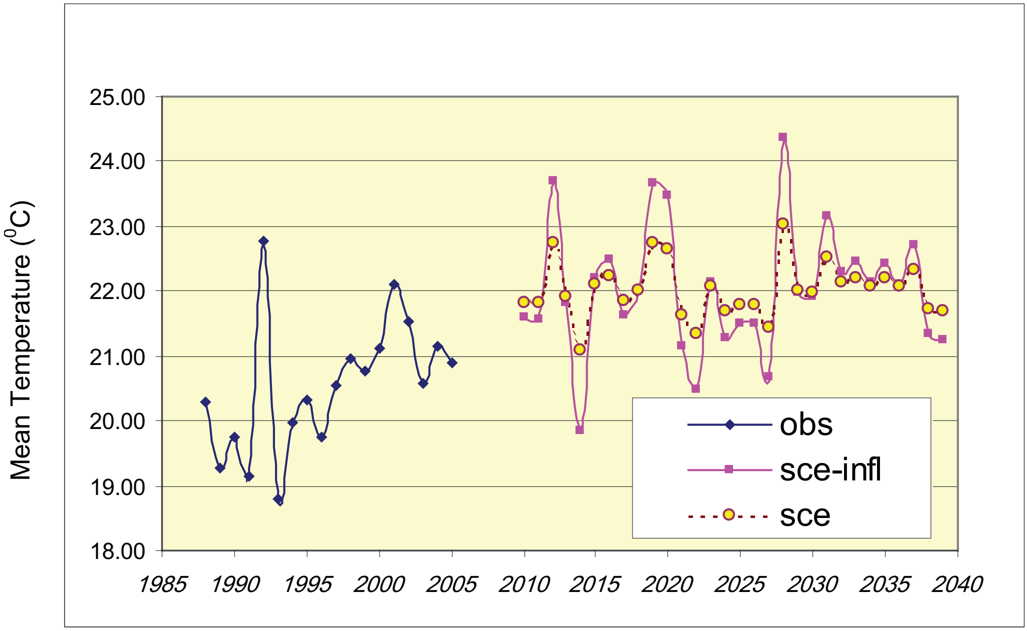

Fig. 9. Observed and predicted mean temperature in the north eastern part of Iran (Babaeyaan et al., 2008): The mean temperature will increase between 1.5^{0}C to 6^{0}C.

3. SUMMARY AND CONCLUSIONS

Climate is an important factor in studying water resources and prediction of the future water availability. To include the effects of climate change in water programs the risks and water vulnerability could be avoided. Some World Meteorological Centers, using sophisticated models have mentioned 2^0 to 4^0 C increase in the mean of the global temperature in the near future. Iran being located in a semi dry and dry zone of the world will also be affected by 2^0 to 4^0 C increase in temperature. The result of many studies shows that negative trends of frost days, freezing days, cool days, cool nights and diurnal temperature range were found over most regions of Iran. There is also positive trends for warm days and nights, over most regions of the country. Positive and negative trends are both the sign of climate change in Iran. According to researches carried out in Iran with consideration of IPCC reports, using GCM models, the mean temperature over Iran will increase substantially. As a result of temperature increase, the demand for water will increase too. It is expected that snow precipitation will be changed toward rain and the area of snow coverage in mountainous regions will be less than last decades. Shorter time of snow coverage will change the season of peak runoff from summer to spring or from spring to winter. As a result of change in precipitation type and precipitation season, a change in runoff and the flow in river is certain. The increase in evaporation also will decrease the flow and intensity of runoff. A survey on historical precipitation data from 600 rainfall stations of IRAN shows a shift of some wet stations to dry stations. According to some investigations, the frequency of dry years in Iran has increased and drought periods have become longer. In the west part of Iran, runoff is a result of snow melting from high level mountains, so by a decrease of snow coverage the runoff will also decrease. Higher evaporation due to increase in temperature will reduce the amount of flow in rivers. The frequency of floods will also be changed and more severe floods may be expected than before. More showers instead of normal rains causes the soil hardness and so water would not easily infiltrate into the soil and ground water recharge will reduce.

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