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TREND ASSESSMENT OF CLIMATE CHANGES IN IRAN

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Abstract

In this paper, according to the data of 40 stations in Iran during 1967-2014, the trend of climate changes and its severity are evaluated. A consistent correlation is highlighted for trends of De Martonne index as indicator of climate change and temperature rise in some stations. Based on the results of the temperature analysis, 70% of the country has become warmer, 3% has become colder and 27% has faced without significant changes. The precipitation in the 30.5% of the country has been decreased and 69.5% of the country didn't show any significant changes. About the climate changes derived from climate index: 38.6 % of the area of the country has become drier and 61.4% of the area didn't show any significant changes. A hazard classification for climate change was used showing 21% of the country under without or no change class, 22% under moderate class, 37.2% under severe class and 19.5% under very severe class. These results correspond to more desertification, frequency and intensity of droughts and observing lost lakes during the last decades in the study area.

Key words: *Iran, Climate change, De Martonne index, trend*

Introduction

Climate change due to global warming is a worldwide public concern. In the third assessment reports of Intergovernmental Panel on Climate Change (IPCC) (Houghton et al., 2001), a warming trend of annual mean temperature was predicted for most parts of Northeast Asia by General Circulation Models (GCMs). In recent years a change in climate has been documented in many locations throughout the world. Increasing rainfall trends were reported in Argentina (Viglizzo et al., 1995), Australia and New Zealand (Suppiah and Hennessy, 1998; Plummer et al., 1999). Decreasing rainfall trends were found in the Russian Federation (Gruza et al., 1999), Turkey (Turkes, 1996, 1998), Africa (Hess et al., 1995; Mason, 1996) and in China (Zhai et al., 1999). In 19 northern and central European weather stations, Heino et al. (1999) found no changes in precipitation extremes. The minimum temperature increased almost everywhere and the maximum and mean temperature increased in northern and central Europe, over the Russian Federation, Canada (Bootsma, 1994) and in Australia and New Zealand (Plummer et al., 1999). These results support the suggestion of Smit et al. (1988) that mid-latitude regions such as the mid-western USA, southern Europe and Asia

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are becoming warmer and drier, whereas the lower latitudes are becoming warmer and wetter. From these studies, however, it is not possible to determine whether the recorded climate change is due to natural climate variability or due to increasing amounts of Green House Gases (GHG) like CO2, CH4 and CFCs in the atmosphere. But only few studies about climate change in Central Asia or Middle East have been mentioned in literatures. Temperature has been increased during the last decades in Central Asia. Aridity is expected to increase across this region, especially in the western parts of Turkmenistan, Uzbekistan, and Kazakhstan. The ability of this western sub-region to adapt to hotter and drier climate is limited by the current water stress and the regional disaster caused by the Aral Sea degradation and poor irrigation practices (Lioubimtseva and Henebry, 2009).

The Intergovernmental Panel on Climate Change (IPCC), in its Fourth Assessment Report defines ‘‘vulnerability’’ as ‘‘the degree to which geophysical, biological and socio-economic systems are susceptible to, and unable to cope with adverse impacts of climate change’’ (IPCC, 2007). In the section 2 of the IPCC paper provides a review of the sample scientific literature on vulnerability, adaptations, and impact assessments based on climate change scenarios. It is crucial to consider adaptations to climate change. Even if GHG emissions were abruptly reduced now, the inertia in the climate system would mean a long period until stabilization (IPCC and WGI, 2007). Vulnerability can also be described as a function of sensitivity to climatic changes, adaptive capacity and exposure to climate hazards (Smit et al., 2001; De Sherbinin et al., 2007). De Sherbinin et al. (2007) continue to argue that vulnerability to the risks of climate change consists of macro forces that come together in different combinations to create unique ‘‘bundles of stresses’’ upon environmental and human systems. Developing countries are vulnerable to extreme weather events in present day climatic variability and this causes substantial economic damage. On an annual basis over the past decade, developing countries have absorbed US$ 35 billion a year in damages from natural disasters. On a per capita gross domestic product (GDP) basis, this is 20 times the cost in the developed world (Freeman, 2001).

Depending on the emission scenarios assumed, continued increases in concentrations of greenhouse gases in the atmosphere are expected to induce an additional 3.58 Celsius degree increase in average global surface temperatures by the year 2100 (Kattenberg et al., 1996). These temperature increases are expected to modify global hydrologic budgets leading to increased winter precipitation at high latitudes, more extreme temperature days, and more or less droughts or floods depending on location (Rind et al., 1990; Kattenberg et al., 1996). Many global and regional assessments of vulnerability to climate change rely primarily on the global climate change scenarios. They focus on the physical aspects of vulnerability, such as land degradation and changes in agricultural productivity (Pilifosova et al., 1997; Mizina et al., 1999; Smit and Skinner, 2002), and on impacts of the availability of water resources to meet future needs (Shiklomanov and Rodda, 2001; Alcamo and Henrich, 2002; Arnell, 2004). Huq and Ayers (2007) have compiled a critical list of the 100 nations most vulnerable to climate change. Under

climate changes, the potential for such projected changes to increase the risk of soil erosion and related environmental consequences is clear, but the actual damage is not known and needs to be assessed (SWCS, 2003). Impacts of projected changes in precipitation, temperature, and CO2 on crop productivity have been evaluated by many researchers (e.g., Rosenzweig and Parry, 1994; Semenov and Porter, 1995; Mearns et al., 1997; Mavromatis and Jones, 1998). Mean and variance changes in both precipitation and temperature were considered in those studies, and some results indicated that changes in climate variability (as measured by variance) could have profound effects on crop productivity. Zhang et al. (2004) developed a downscaling method that can be used to directly incorporate changes in monthly precipitation and temperature distributions including mean and variance into daily weather series using a stochastic weather generator (CLIGEN) developed by Nicks and Gander (1994). It seems more likely that, in global terms, implications of climate change depend on how changes in climate relate to other changes and stresses, i.e., how climate change operates in a multi-stress context, related to such issues as limits/thresholds and adaptive behavior (Parson et al., 2003). The links between sustainable development and climate change are deep, multiple and varied (see, Cohen et al., 1998; Rayner and Malone, 1998; Banuri and Gupta, 2000; Munasinghe, 2000; Robinson and Herbert, 2001).
In the present paper, we focus on the climatic changes over the last decades, in all part of Iran country. It is assumed when temperature is increased during a period of years, trend of aridity indices is decreased during that time. However, this global trend should be qualified at the regional scale where both increasing and decreasing trends are identified.

Materials and methods

Study Area

Iran was selected as a study area (Fig. 1) for a test assessment of climate change. Iran is situated in South-West Asia, at the crossroads of the Middle East. Iran borders on the Caspian Sea in the north and the Persian Gulf and the Gulf of Oman in the south. Iran shares borders with seven countries: Armenia, Azerbaijan, Afghanistan, Iraq, Pakistan, Turkey and Turkmenistan. It covers an area of 1648195 km^2, which lies between the latitudes of 25° 14´ and 39° 42´ N and the longitudes of 44° 10´ and 63° 11´ E. The population of the country has increased from 34 million in 1978 before of the revolution to 68 million in 2006, showing double increase during less than thirty years.
The elevation varies between the see level to around 5,604m in Damavand mountain. Most of Iran's territory is covered by mountains. It has the Alborz Range in the north and the Zagros mountain system in the south-west. Iran is divided to eight major basins on the basis of hydrology and topography. In Iran, there are no large rivers and there is only one navigable river, the Karun. The Karun starts in the Zagros and runs mainly through the territory of Khuzestan in the south-west of

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the country. The total length of the river is 950 km. Other rivers flowing through Iran include the Sefidrud, the Karkheh, the Zayanderud, the Dez, the Atrak, the Aras and the Mond that flow to the Persian Gulf, Caspian Sea and internal plains. The climate differs but in most part of the country is arid and semi arid with a mean annual rainfall range of 50-2000 mm. Precipitation in some central parts of Iran is about 50 mm, while it can reach up 2000 mm per year on the northern slopes of the Alborz Range and the South Caspian lowlands. Average precipitation of this country is 245 mm per year. The average temperature stands at +2°C in January and +29°C in July. The main period of precipitation is during winter (60% of total rainfall).

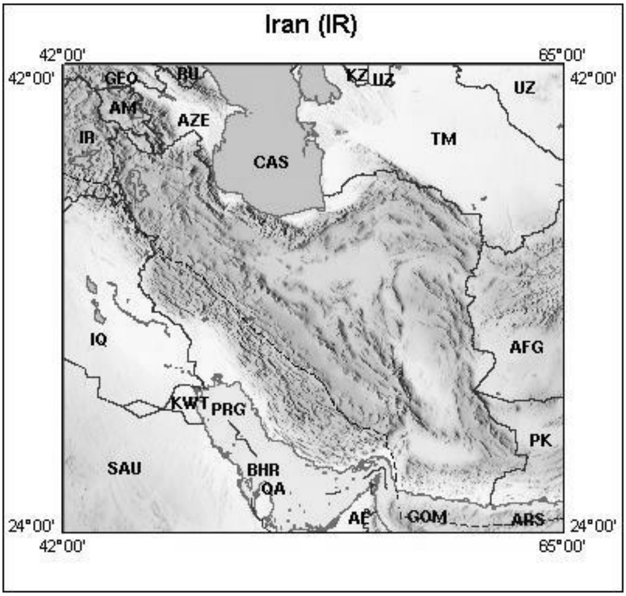

Figure 1
Study area

Data and methodology

The meteorological data used in this study, consisting of monthly precipitation and temperature measurements for 40 synoptic stations distributed fairly evenly in the country (Fig. 2), were collected from the Iran Meteorological Organization (IMO). In the present work, to determine the adequate quantity of station with suitable scatter equations [1] and [2] (Mahdavi 2002) was used. An exhaustive list of the selected stations is given in Table 1.

$$N = \left(\frac{CV\%}{E\%}\right)^2 \quad [1]$$

$$CV\% = \frac{SD}{\overline{P}} \times 100 \quad [2]$$

N = minimum of adequate station number (In this study: N=48)
CV% = average of coefficient of variations of annual precipitation for synoptic stations of Iran
E% = acceptable faults (%) for the determination of correct number, for this work E% is considered 15%
SD = standard deviation of annual precipitation for synoptic stations of Iran
$\overline{P}$ = annual precipitation average for synoptic stations of Iran

To determine the common duration of the suitable statistic period for all the stations, equation 3 (Mahdavi 2002) was used. Using that, 37.5 years is the at least number of years which are needed for the current study. The length of the data used in this study include from 1 January 1967 to 31 December 2014 for the total of stations. For each station, missing values are estimated using a linear regression with the ''optimum'' reference station.

$$N = \left(4.3t \times \log R\right)^2 + 6 \quad [3]$$

(In this paper: N=37.5 years)
t = t student with the freedom degree of n-6
R= Ratio of return period precipitation of 100 years to 2 years

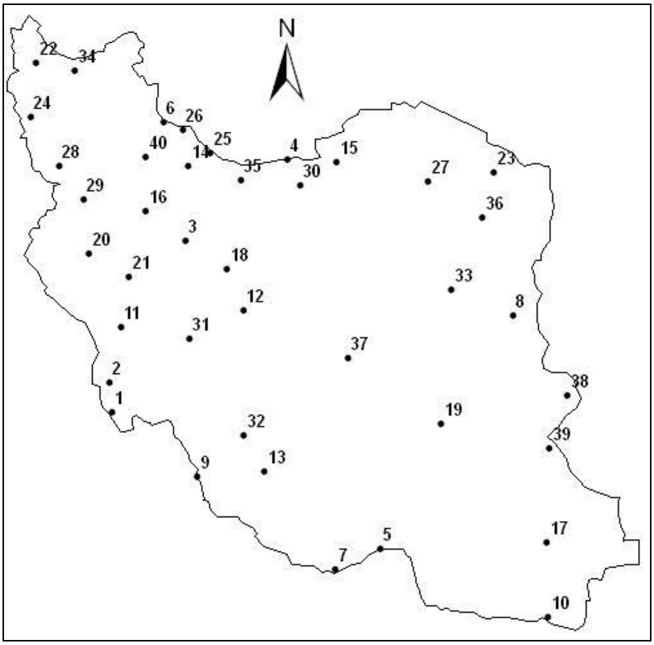

Figure 2
Scattering of stations in Iran map

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Table 1
Name of the selected stations over the study area

Map location	Station name	Latitude (n)	Longitude (e)	Elevation (m)
1	abadan	30° 22'	48° 15'	6
2	ahvaz	31° 20'	48° 40'	22
3	arak	34° 6'	49° 46'	1708
4	babolsar	36° 43'	52° 39'	-21
5	bandar abbas	27° 13'	56° 22'	10
6	bandar anzali	37° 28'	49° 28'	-26
7	bandar lenge	26° 32'	54° 50'	23
8	birjand	32° 52'	59° 12'	1491
9	bushehr	28° 59'	50° 50'	20
10	chabahar	25° 17'	60° 37'	8
11	dezful	32° 24'	48° 23'	143
12	esfahan	32° 37'	51° 40'	1550
13	fassa	28° 58'	53° 41'	1288
14	ghazvin	36° 15'	50° 3'	1279
15	gorgan	36° 51'	54° 16'	13
16	hamedan	35° 12'	48° 43'	1697
17	iran shahr	27° 12'	60° 42'	591
18	kashan	33° 59'	51° 27'	982
19	kerman	30° 15'	56° 58'	1753
20	kermanshah	34° 21'	47° 9'	1318
21	khoram abad	33° 26'	48° 17'	1147
22	khoy	38° 33'	44° 58'	1103
23	mashhad	36° 16'	59° 38'	999
24	oroomieh	37° 32'	45° 5'	1315
25	ramsar	36° 54'	50° 40'	-20
26	rasht	37° 15'	49° 36'	-6
27	sabzevar	36° 12'	57° 43'	977
28	saghez	36° 15'	46° 16'	1522
29	sanandaj	35° 20'	47° 0'	1373
30	semnan	35° 35'	53° 33'	1130
31	shahre kord	32° 17'	50° 51'	2048
32	shiraz	29° 32'	52° 36'	1484
33	tabass	33° 36'	56° 55'	711
34	tabriz	38° 5'	46° 17'	1361
35	tehran	35° 41'	51° 19'	1190
36	torbat hydarieh	35° 16'	59° 13'	1450
37	yazd	31° 54'	54° 17'	1237
38	zabol	31° 2'	61° 29'	489
39	zahedan	29° 28'	60° 53'	1370
40	zanjan	36° 41'	48° 29'	1663

In the next stage, for each station in every year, annual precipitation, average of annual temperature and De Martonne index were calculated (Table 2).

Table 2
Table of annually statistically characteristics of Tehran station

Year	Annual precipitation (mm)	Average of annual temperature (°C)	De Martonne index *
1967	105.5	16.4	3.98
1968	223.9	16.7	8.37
1969	399.4	15.8	15.45
…			
2012	239.7	17.7	8.63
2013	157.6	18.4	5.53
2014	93.5	18.5	3.28

* De Martonne index = ($\frac{\overline{P}}{T+10}$); $\overline{P}$: annual precipitation average and

T: average of annual temperature during the period

An annually trend was used as it allowed a precise study of the inter-annual fluctuations of the climatic data of these stations. The key difficulty encountered in the analysis of the fluctuations in the climatic data of stations is the multi-scale property of the signal in relation to several hydrological processes. Monthly fluctuations generally reflect the occurrence of low or high intensity events. Annual fluctuations record the variations of the annual water budget highlighting dry and humid years. Multi-annual fluctuations reflect the largest scale variations related to global general meteorological circulations and long term climate change.
Therefore in this stage, three graphs were prepared for each station showing trends of average of annual temperature, annual precipitation and De Martonne index (Fig. 3). ''Year to year'' fluctuations of the climate indices display a succession of dry and humid periods. Trend analysis method involved linear regression was used for the data in the current work. Linear trend analysis indicated the tendency rate (slope) using least squares at the 95% confidence level. The Pearson correlation coefficient (two-tailed) was calculated to measure the trend analysis and to show those trends which were significant.

Results and discussion

Linear regression analysis for climate indices during the period of study showed increasing trends in temperature and dryness with time in most of stations (Table 3). In this stage, by using the results of Table 3 an influenced zone for each station (specified by thiessen method (Makhdoum *et al.*, 2001): dividing areas with some points to different polygons equaled to numbers of points based on the nearest distance to each point) was considered to prepare a map showing climate changes since 48 years ago to now (Fig. 4).

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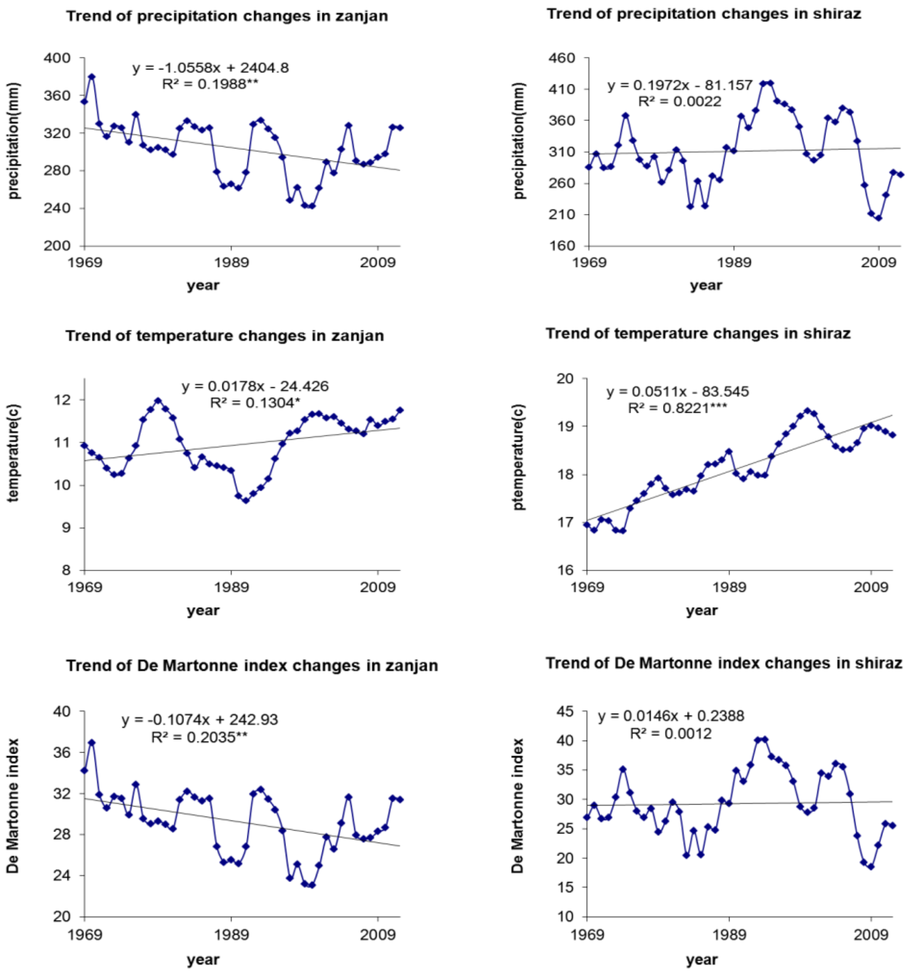

Figure 3. *Trend of climate indices in two stations of Shiraz and Zanjan (*: significant in level 0.05, **: significant in level 0.01, ***: significant in level 0.001)*

Our results from Table 3 and Figure 4 indicated remarkable differences among the stations with negative and positive trends for different parameters. Based on result of this research in case of temperature changes during the period of study, 70% of the extent of the country has become warmer than before at 90%, 95% and 99% confidence levels, while 3% has become colder at 90%, 95% and 99% confidence levels and 27% of the land didn't show any significant changes in the temperature trends. Those parts which have become colder were located more along Zagros Mountains in the high elevations of the country where industry development is limited.

Table 3. *Trend of climate parameters changes in some stations*.

Code	Station name	Trend of precipitation change	Trend of temperature change	Trend of De Martonne index change
1	Abadan	Without significant change	Warmer in significant level of 0.001	Drier in significant level of 0.1
2	Ahvaz	Decrease in significant level of 0.05	Warmer in significant level of 0.001	Drier in significant level of 0.01
3	Arak	Decrease in significant level of 0.05	Warmer in significant level of 0.001	Drier in significant level of 0. 01
4	Babolsar	Without significant change	Warmer in significant level of 0.001	Without significant change
5	Bandar Abbas	Without significant change	Without significant change	Without significant change
6	Bandar Anzali	Without significant change	Warmer in significant level of 0.001	Without significant change
7	Bandar Lenge	Without significant change	Warmer in significant level of 0.001	Without significant change
8	Birjand	Without significant change	Without significant change	Without significant change
	…..			
35	Tehran	Without significant change	Warmer in significant level of 0.001	Without significant change
36	Torbat Hydarieh	Decrease in significant level of 0.1	Without significant change	Drier in significant level of 0. 1
37	Yazd	Without significant change	Warmer in significant level of 0.001	Without significant change
38	Zabol	Decrease in significant level of 0.05	Warmer in significant level of 0.001	Drier in significant level of 0. 05
39	Zahedan	Without significant change	Warmer in significant level of 0.001	Without significant change
40	Zanjan	Decrease in significant level of 0.01	Warmer in significant level of 0.1	Without significant change

On the other hand, those parts showing higher increasing (2-3°C increase) were those stations located in big cities of country with population of more than one million. In urban areas, the urban heat island (UHI) effect caused by land-use change from urbanization and industrialization exacerbate the warming in climate, signifying the impact of climate change (Arnfield, 2003; Hinkel et al., 2003). It was reported in a recent study that several mega-cities in Asia have experienced intense surface UHIs which raised the urban air temperature by 4–12°C during dry seasons (Hung *et al.*, 2006).

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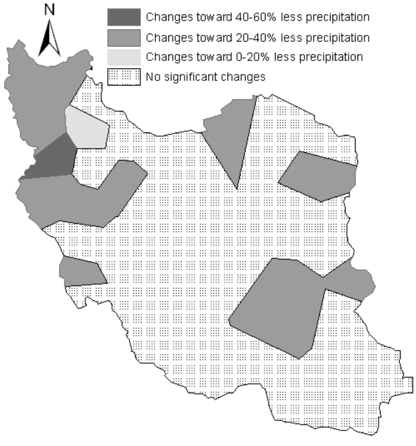
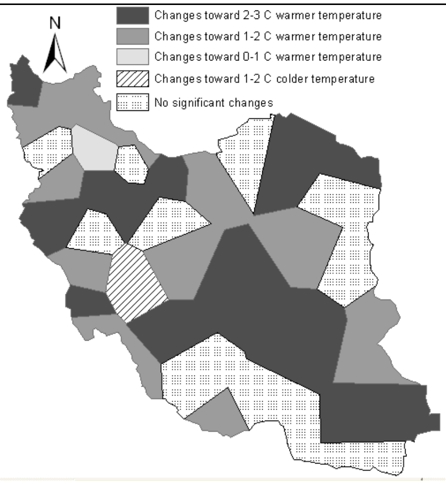
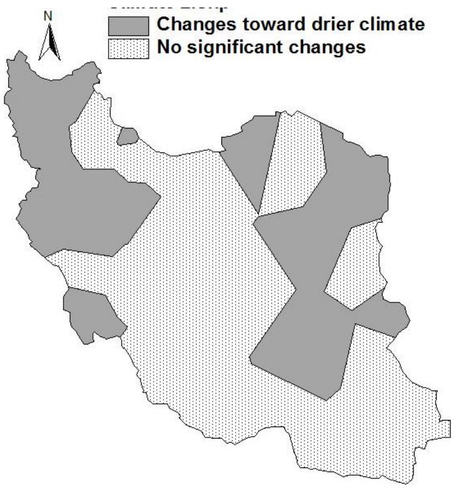


a) Precipitation changes



b) Temperature changes



c) Climate changes

Figure 4
Trend maps of changes for precipitation, temperature and climate index of De Martonne during the period of 1967-2014.

On the other hand, precipitation trends during the period of study show 30.5% of the country has been decreased at 90%, 95% and 99% confidence levels, while in 69.5% of the land didn't show any significant changes. Most of decreasing was observed in the western and some parts of eastern parts. These results confirm those studies in the region showing trend of drought occurrence in the some parts of study area have been increased (Zareiee, 2009; Asrari and Masoudi, 2010; Masoudi and Afrough, 2011)..

Also about climate change in the country using trends of De Martonne index, 38.6% of the extent of the country has become drier than before at 90%, 95% and 99% confidence levels, while 61.4% of the land didn't show any significant changes. Most of the lands which showed drier condition than before were

observed more in the western and eastern parts of the country showing good agreement with those parts with decreasing in precipitation during the period.
Also a hazard classification (Asrari and Masoudi, 2010) using of temperature changes trend and De Martonne index changes trend (Table 4) was used to show and classify climate changes in the form of hazardous classes for the thiessen zone of each station (Fig. 5).

Table 4. *Hazard classification for trend of climate changes.*

Symbol	**Hazard classes**	**Description of hazard classes**
1	Without hazard	Without changes in climate and increasing of temperature
2	Slight hazard	Significant changes in temperature (< 1 °C increase in temperature during 100 years), Without significant changes in climate index trend
3	Moderate hazard	Significant changes in temperature (between 1- 4°C increase in temperature during 100 years), Without significant changes in climate index trend
4	Severe hazard	Significant changes in temperature (> 4°C increase in temperature during 100 years) **or** significant changes in decreasing of climate index trend toward drier condition
5	Very severe hazard	Significant changes in temperature (> 4°C increase in temperature during 100 years) **and** significant changes in decreasing of climate index trend toward drier condition

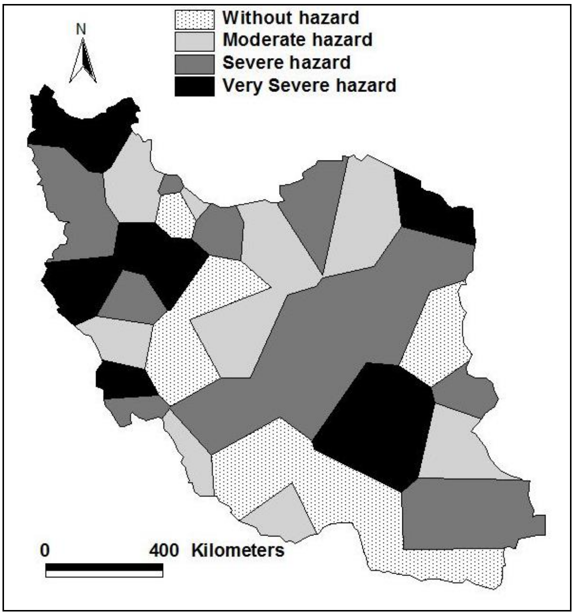


Figure 5
Hazard map of climate changes showing different hazard classes.

From the Fig. 5, it is concluded that in the country areas under moderate to very severe hazard of climate changes (79%) were more widespread compared to areas under without hazard condition. This implies the obvious that climate changes in

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Iran with more arid climate are worse compared to many countries. Among the severity classes a greater proportion (37.24%) of land was under ‘severe hazard’ in Iran while areas under ‘very severe hazard’ covered 19.52%, areas with 'moderate hazard' covered 22.01% and 21.23% of the country showed none hazard class for climate changes.
This work provides the evidence demonstrating the link between the drought hazard and the intensification of aridity in most parts of Iran especially in the severe and very severe hazard areas (Masoudi and Hakimi, 2014). This corresponds to more desertification (Masoudi, 2010), degradation and lowering of water resources especially ground water (FAO, 1994), social and economic impacts of drought like immigration from villages in recent decades, those studies showing climate changes is going to drier condition and observing lost lakes like Orumieh lake during the last decade in the study area (Asrari et al., 2012).

Conclusion

Annual precipitation and annual average of temperature data for 40 meteorological stations from 1967–2014 in the country were analyzed for temporal and spatial trends. The methods used included the simple regression analysis. From the Fig. 6, it is concluded that in the country a greater portion of land during the period of study has become warmer than before.

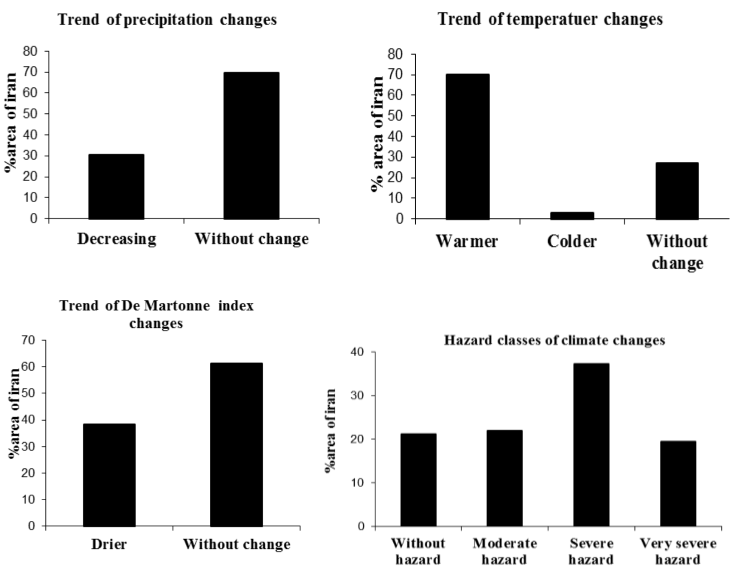

Figure 6 *Percent land under different climate indices changes and hazard classification.*

This confirms overall global warming in the world. Also those areas showing decreasing in precipitation during the time were about one third of Iran. The results derived from the trends of climate index confirm this fact that the overall climate of the country has become worse than before because about 40% of lands have become drier. A hazard classification for climate change was used in the research that can be used in the other countries also. Overall results derived from the work and based on this kind of classification indicated that areas under higher hazard of climate changes were more widespread compared to areas under less hazardous condition.

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