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Trend assessment of climate changes in Khuzestan Province, Iran

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Abstract
In this paper, according to the data of 17 weather stations in Khuzestan during 1951–2012, the trend of climate changes and its severity were evaluated. A consistent correlation was highlighted for trends of De Martonne index as indicator of climate and temperature index in some stations. Based on the results of the temperature analysis, 88.31% of the Province became warmer, 6.3% became colder, and 5.3% did not show significant changes. The precipitation in the 7% of the province increased, in 67.2% of the area decreased, and 25.8% of the province did not show any significant changes. About the climate changes: 67.2% of Province became drier and 32.7% of the area showed no significant changes. A hazard classification was used for climate change based on trends of temperature and the aridity index of De Martonne during the period. The results showed 18.8% under moderate class, 40.3% under severe class, and 40.9% very severe class. This contribution provided the first experimental data-based evidence demonstrating the link between the global warming and the intensification of aridity in most parts of Khuzestan. This finding concluded more desertification and frequency and intensity of droughts.

Keywords
climate change, De Martonne index, Khuzestan, temperature.

1. 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 changes in climate were documented in many locations throughout the world. Increasing rainfall trends were reported in Argentina (Viglizzo et al., 1995), Australia, and New Zealand (Suppiah & Hennessy, 1998; Plummer et al., 1999). Decreasing rainfall trends were found in the Russian Federation (Gruza et al., 1999), Turkey (Türke¸s, 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). The results supported the suggestion of Smit et al. (1988) that mid-latitude regions such as the mid-western USA, southern Europe, and Asia became warmer and drier, whereas the lower latitudes became 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

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increasing amounts of Green House Gases (GHG) like CO_2, CH_4, and CFCs in the atmosphere. A few studies about climate change in Central Asia or Middle East was in literature. Temperature has increased during the last decades in Central Asia. Aridity was 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 was limited by the current water stress and the regional disaster caused by the Aral Sea degradation and poor irrigation practices (Lioubimtseva & Henebry, 2009).

The IPCC Fourth Assessment Report defined ‘‘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 provided 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, the inertia in the climate system would mean a long period until stabilization (IPCC & 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) continued 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 were vulnerable to extreme weather events in climatic variability and this caused substantial economic damage. On an annual basis over the past decade, developing countries absorbed US$ 35 billion a year in damages from natural disasters. On a per capita gross domestic product (GDP) basis, this was 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 focused on the physical aspects of vulnerability, such as land degradation and changes in agricultural productivity (Pilifosova et al., 1997; Mizina et al., 1999; Smit & Skinner, 2002), and on impacts of the availability of water resources to meet future needs (Shiklomanov & Rodda, 2001; Alcamo & Henrich, 2002; Arnell, 2004). Huq and Ayers (2007) 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 CO_2 on crop productivity were evaluated by many researchers (e.g., Rosenzweig & Parry, 1994; Semenov & Porter, 1995; Mearns et al., 1997; Mavromatis & 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 could 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 depended on how changes in climate related to other changes and stresses, i.e., how climate change operated 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 & Malone, 1998; Banuri & Gupta, 2000; Munasinghe, 2000; Robinson & Herbert, 2001).

In the present paper, we focus on both the climatic changes and temperature changes over the last decades, in all parts of Khuzestan Province. It is assumed when temperature increases during a period of years, trend of aridity indices decreases during that time. However, this global trend should be qualified at the regional scale where both increasing and decreasing trends are identified.

2. Study area

Khuzastan was selected as a study area (Fig. 1) for an assessment test of climate change. Khuzastan is situated in South-West of Iran. It covers an area of 63633 km^2, which lies between the latitudes of 29° 57´ **N** and 33° 00´ N and the longitudes of 47° 40´ **E** and 50° 33´ E. The elevation varies between the see level to around 3,500m in Sefidkoh mountain. About 30% of Khuzestan territory is covered by mountains. It has the Zagros system range in the north, east, and south-east. In Khuzestan, there are large rivers and only one navigable river; the Karun. The Karun starts in the Zagros and runs mainly through the territory of Khuzestan. The total length of the river is 950 km. Other rivers flowing through the province include the Karkheh, and the Dez. Climate differs widely but most parts of the province are arid and average of precipitation is 266 mm per year, but mean annual rainfall reach to 950 mm in the north eastern parts. The main period of precipitation is during winter. Temperature in most parts reaches above 50°C during summer.

3. Materials and Methods

The meteorological data used in this study, consisting of monthly precipitation and temperature measurements for 17 synoptic and rainfall stations distributed fairly evenly in the province (Fig. 1), were collected from the Iran Meteorological Organization (IMO) and Water Organization of province. An comprehensive list of the selected stations is given in Table 1. The data used in this study are from 1 January 1951 to 31 December 2012.

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

Table 1. Selected stations over the study area

Map location (code)	Station name	Latitude	Longitude	Elevation (m)
1	Ahvaz	31°19' N	48°39' E	22.5
2	Abadan	30°21' N	48°14' E	6.6
3	Bostan	48°0' N	31°42' E	7.8
4	Dezfol	48°22' N	34°23' E	82.5
5	Izeh	49°51' N	31°50' E	840
6	Mahshahr	49°8' N	30°32' E	6.2
7	Masjed soliyman	49°16' N	32°55' E	230.5
8	Ramhormoz	49°35' N	31°15' E	150.5
9	Omidiye	49°38' N	30°45' E	27
10	Sosan	49°51' N	31°58' E	600
11	Sadedez	48°25' N	32°34' E	525
12	Paypol	48°08' N	32°24' E	90
13	Hamidiye	48°25' N	31°29' E	12
14	Gotvand	48°49' N	32°14' E	76
15	Talezang	48°46' N	54°16' E	440
16	Rodzard mashin	35°12' N	32°49' E	354
17	Shohada behbahan	50°13' N	30°35' E	333

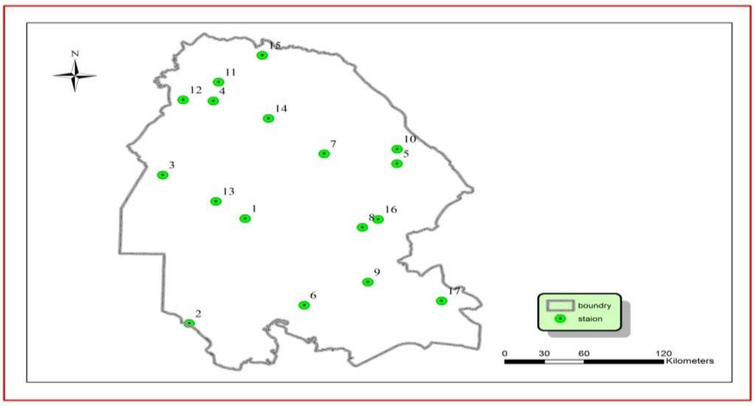


Fig. 1. Distribution of stations in this study

Table 2. Annual statistical characteristics of Ahvaz station

Year	Annual precipitation (mm)	Average of annual temperature (°C)	De Martonne index*
1958	279.4	24.6	8.08
1959	131.2	25.7	3.08
1960	120.1	24.6	3.42
…			
2011	231	26.2	6.3
2012	89.3	26.1	2.47

* De Martonne index = ($\frac{\overline{P}}{T+10}$), $\overline{P}$: annual precipitation average, and *T*: average of annual temperature during the period.

The annual trend is used to precise study of the inter-annual oscillations 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, three graphs were prepared for each station showing trends of average of annual temperature, annual precipitation, and De Martonne index (Fig. 2). ‘‘Year to year’’ oscillations of the climate indices display a succession of dry and humid periods. Also five-year moving average of data for indicators was superimposed in order to highlight the general tendency. The trend analysis method involved with linear regression was used for the five-year moving average of data in the current work. The 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.

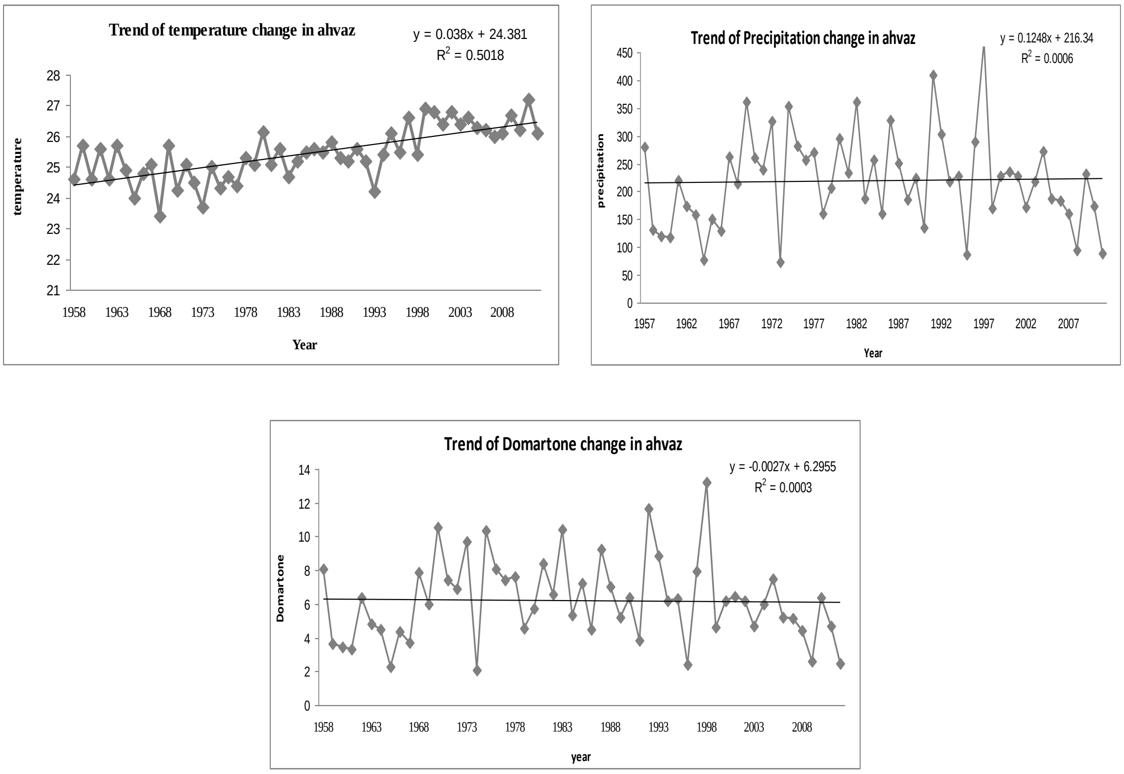


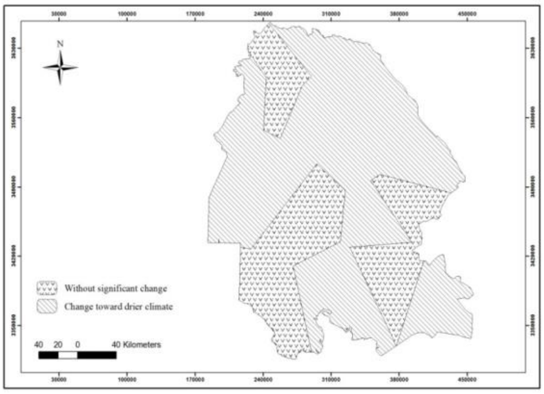
Fig. 2. **Trend of climate indices using five-year running mean in one stations of Ahvaz**

4. Results and Discussion

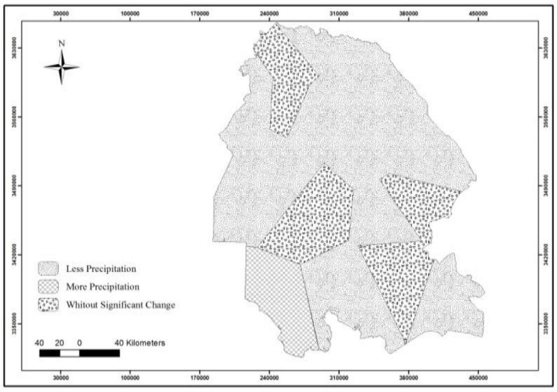
Linear regression analysis for climate indices during the period of the study suggested increasing trends in temperature and dryness with time in most of stations (Table 2). Using the results in Table 2, an influenced zone for each station specified by Thiessen method (Makhdoum et al., 2001) was considered to prepare a map showing climate changes since 17 years ago to now (Fig. 3). The method divides areas with some points to different polygons equaled to numbers of points based on the nearest distance to each point.

Table 3. Trend of climate's parameters changes in each station

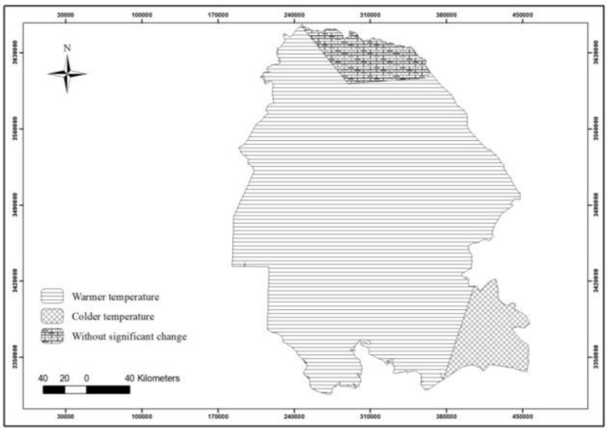
Code	Station Name	Trend of precipitation change	Trend of temperature change	Trend of De Martonne index change
1	Ahvaz	Without significant change	Warmer in significant level of 0.001	Without significant change
2	Abadan	Increase in significant level of 0.1	Warmer in significant level of 0.001	Without significant change
3	Bostan	Decrease in significant level of 0.001	Warmer in significant level of 0.01	Drier in significant level od 0.001
4	Dezfol	Without significant change	Warmer in significant level of 0.01	Without significant change
5	Izeh	Decrease in significant level of 0.01	Warmer in significant level of 0.05	Drier in significant level of 0.001
6	Mahshahr	Decrease in significant level of 0.01	Warmer in significant level of 0.001	Drier in significant level of 0.01
7	Masjed Soleman	Decrease in significant level of 0.05	Warmer in significant level of 0.01	Drier in significant level of 0.001
8	Ramhormoz	Decrease in significant level of 0.05	Warmer in significant level of 0.001	Drier in significant level of 0.001
9	Omidiye	Without significant change	Warmer in significant level of 0.001	Without significant change
10	Sosan	Decrease in significant level of 0.05	Warmer in significant level of 0.05	Drier in significant level of 0.001
11	Sad Dez	Without significant change	Warmer in significant level of 0.1	Without significant change
12	Paaypol	Decrease in significant level of 0.001	Warmer in significant level of 0.1	Drier in significant level of 0.001
13	Hamidiye	Decrease in significant level of 0.01	Warmer in significant level of 0.001	Drier in significant level of 0.001
14	Gotvand	Decrease in significant level of 0.001	Warmer in significant level of 0.01	Drier in significant level of 0.001
15	Talezang	Decrease in significant level of 0.05	Without significant change	Drier in significant level of 0.01
16	Mashin	Without significant change	Warmer in significant level of 0.05	Without significant change
17	Shohada Behbahan	Decrease in significant level of 0.05	colder in significant level of 0.05	Drier in significant level of 0.001



a) Climate changes



b) Precipitation changes



c) Temperature changes

Fig. 3. Trend maps of changes for precipitation, temperature and climate index of De Martonne during the period of 1951-2012.

Our results from Table 3 and Figure 3 indicate remarkable differences among the stations with negative and positive trends for different parameters. Based on the results in case of temperature changes during the period of the study, 88.31% of the extent of the Province became warmer than before at 90%, 95% and 99% confidence levels, while 6.3% became colder at 95% confidence level, and 5.3% of the land did not show any significant changes in the trends. Colder Part is located along Zagros Mountains in the high elevations where industry development is limited and also is near to a dam. On the other hand, those stations showing higher increase (2-3°C) are in the big cities of the province with population of more than half million or where the industrial activity is higher than other places. 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 experienced intense surface UHIs which raised the urban air temperature by 4–12°C during dry seasons (Hung et al., 2006).

The precipitation trends showed that 7% of the extent of the province increased at 90% confidence level, while in 67.2% of the province decreased at 95% and 99% confidence levels, and 25.8% of the land did not show any significant changes. Most of the reduction was observed in the northern half parts especially in the northeast while most of area showing increase and without change in precipitation were observed in the southern half parts especially in the southwest.

The climate change in the province using trends of De Martonne index, 67.2% of the extent of the Province became more arid at 99% confidence level, and 32.7% of the land did not show any significant changes. Most of the drier lands were observed more in the northern and eastern parts of the province.

A hazard classification (Asrari & Masoudi, 2010) using temperature changes trend and De Martonne index changes trend (Table 4) was used to show and to classify climate changes in the form of hazardous classes for the Thiessen zone of each station (Fig. 5).

From the Figure 4, it is concluded that in the province, the areas with severe and very severe hazard of climate changes (81%) were more widespread compared to the areas with less hazardous condition. This obviously implies that the climate changes in Khuzestan with drier climate become worse compared with many other places in the country. Among the severity classes, a greater proportion of land (40.9%) is under 'very severe hazard' in Khuzestan and after that the areas under 'severe hazard' cover 40.3%, while the areas with 'moderate hazard' cover 18.8%.

Table 4. Hazard classification for trend of climate changes (Asrari & Masoudi, 2010)

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

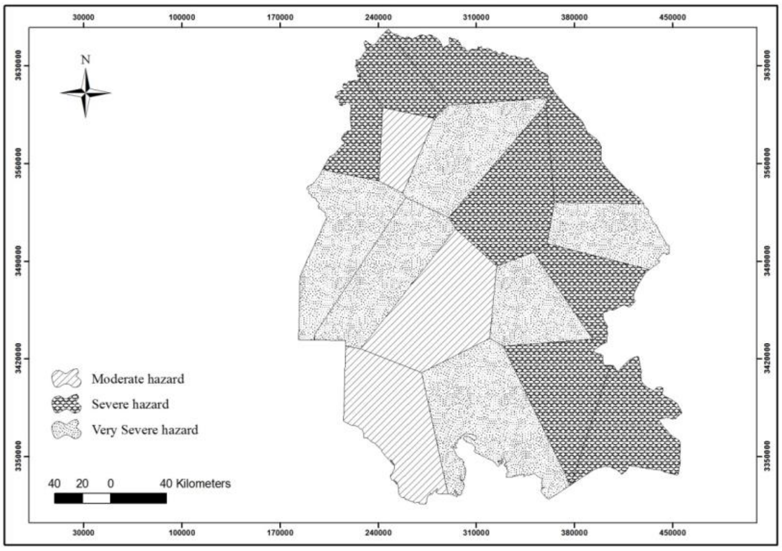


Fig. 4. Hazard classification map for trend of climate changes

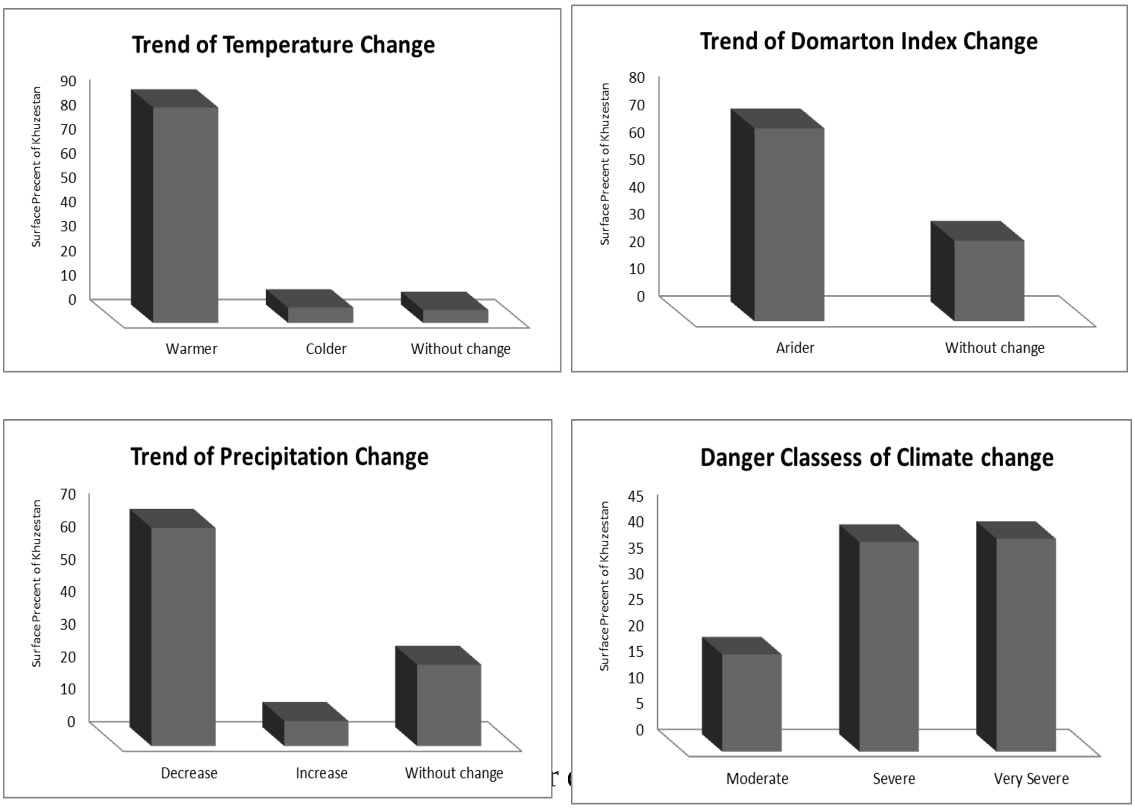


Fig. 5. Percent of the land under different climate indices changes

5. Conclusions

Annual precipitation and annual average of temperature for 17 meteorological stations from 1950–2012 in Khuzestan province were analyzed from temporal and spatial trends point of view. The methods used include the simple regression analysis. Results showed that in the province, a greater portion of land during the period of the study became warmer than before. This confirmed the overall global warming in the world. Furthermore, those areas showing decreasing in precipitation during this time were more widespread compared with those areas with increasing trend and without any changes. The results derived from the trends of climate index confirmed this fact that the overall climate of the province became worse because more than 67.2% of the lands showed that Khuzestan goes towards the drier condition. The hazard classification for climate change was used in the research can be used in other places. Overall, the results based on this classification indicated that the areas under very severe and severe hazards (81%) were more extensive than the moderate hazard.

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