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Assessing Direction of desertification changes in an Arid Region (A Case study: Semnan County, Iran)

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Abstract

Desertification is a serious ecological, environmental, and socio-economic threat to the world, and there is an urgent need to develop rational methods for its evaluation at different spatio-temporal scales. This study aimed to address the main directions of desertification changes in Semnan County, Iran. Monthly precipitation was used to calculate a 12-month SPI (Standardized Precipitation Index) and the normalized difference vegetation index (NDVI) obtained by Landsat Thematic Mapper (TM) sensor of April month were used for the three years, *viz.*, 1987, 1998, and 2011. Five major categories were identified at level-I and they were subdivided into 11 categories including, 1. Residential areas, 2. Vegetation, 3. Bare and rocky areas, 4. Salt lands and 5. Sand areas. The results indicated that the reduction of the NDVI values was consistent with the changes in land use/land cover. This progress was taken place in some areas with the development of bare soil to salt land, and in some areas with the expansion of sand land, particularly from 1987 to 1998. The results indicated that the salt lands increased 348.24 and 721.57 square kilometers from 1987 to 1998 and from 1998 to 2011, respectively. The results revealed that desertification occurred at a rapid rate, especially towards the east and southeast directions in the study area. That was, towards the Dasht-e-Kavir and Damghan City. The results showed that besides using NDVI and SPI for drought monitoring, the meteorological variables such as temperature, sunshine hours and evaporation could improve the accuracy of interpretation of the results.

Keywords: Land Degradation; Land use changes; NDVI; Semnan County

1. Introduction

Dryland can be further subdivided as arid, semi-arid and sub-humid which approximately cover 5.2 billion hectares or about 40% of the land surface of the globe. It is being sharply increased as a result of population growth and climate change (White *et al.*, 2003). Over two billion people live in drylands: 42% of the Asian population, 41% of Africans, and 25 to 30% of the rest of the world. Desertification is a term which used since 1949 when Aubreville thought that desertification was the change in arable land into a desert as a result of degradation of land by man-induced soil erosion (Dregne, 1986). Desertification defines as "land degradation in arid, semiarid and dry-sub humid areas resulting from various factors including climate variations and human activities (UNCCD, 1992). Desertification is a serious ecological, environmental, and socio-economic threat to the world, and there is an urgent need to develop rational and repeatable methods for its evaluation at different scales (Aslinezhad *et al.,* 2014; Lamchin *et al.,* 2015). Desertification is usually accompanied by changes that have remained for decades and likely to be permanent and irreversible. Desertification is caused by a combination of factors that change over time and vary by location. These include land degradation, changes in rainfall regime and change in composition of vegetation and biodiversity (D'Odorico *et al*, 2013, p 326). Other factors that affect desertification include wind and water erosion, rising runoff and flood risk, salinity of agricultural land and reducing soil fertility, reducing surface and ground water, threatening residential areas, industries, health threats to the

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inhabitants of the region and poverty and migration, (Rayegani *et al.*, 2013).

Today, the need for more accurate knowledge of the effective factors and mechanisms of desertification is felt more and more in order to properly manage and plan the desert areas (Jafari and Bakhshandehmehr, 2013; Kardavani, 2010). Remote sensing data for natural resources management and food security has become in recent years a very powerful tool (Alavipanah, 2003; Kumar, and Shekhar, 2015; Fellah *et al.*, 2017). Bazgeer *et al*. (2008) studied land use change detection in Balachaur watershed in Punjab, India during 1984 and 2003. The results showed that due to forestry and forest protection, vegetation density in the region increased and changes in climate variations were affected at the micro level. Hadeel *et al*. (2010) utilized the integrated remote sensing and GIS in the southern part of Iraq (Basrah) to assess the environmentally sensitivity area to desertification. The thematic layers of soil, vegetation, climate, and extent of sand movement were used. These used satellite images of TM in 1990 and ETM$^+$ in 2003 and field survey data. They found that highly sensitive areas for sandy desertification were located in the western–southern parts of Basrah Province, the rest of the southern parts of the study location exhibit moderately sensitive areas for desertification, the northern parts of the study location were very low and low sensitive to desertification. Matinfar *et al*. (2013) also detected the soil salinity changes during the period 1975–2004 in the Ardakan area located in the the central deserts of the Iranian plateau. The Landsat MSS and TM on two different dates of September 14, 1975 and September 11, 2004, respectively, were used. The result classified images showed that about 39% of the total area had changed during 29 years. The result of this study also revealed that the possibility of detecting important soil salinity changes using Landsat satellite data. Negaresh *et al*. (2016) studied the factors influencing desertification progress to help the reduction damage of this phenomenon. The study proceeded to zone Sistan and Baluchestan Province using three analytic hierarchy processes, Expert Choice software and a geographic information system. Factors were used as follows: climatic elements, morphology and human factors. The results showed that, there were five desertification hazard regions in Sistan and Baluchestan Province with an area of about 187502 km^2 and high hazard regions covering the Province in the north. Lamchin *et al*. (2015) used Landsat TM/ETM$^+$ data on a local scale to assess land cover change and desertification in Mongolia. NDVI (Normalized Difference Vegetation Index), TGSI (Topsoil Grain Size Index), and land surface albedo were selected as indicators to detect changes in land surface conditions in terms of vegetation biomass, landscape pattern, and micrometeorology. The analysis showed there was no correlation between NDVI and albedo or TGSI but a high correlation observed between TGSI and albedo. Strong correlations between TGSI and albedo were found in the non-desertification areas. They also showed that there was a decrease in areas of zero and low desertification from 2002 to 2011, and an increase in areas of high and severe desertification. Arastoo and Ghodrati, (2014). They used SPOT Normalized Difference Vegetation Index (NDVI) to find changes from 1999 to 2009 in Semnan Province. They found that in past decades, the area of environmentally valuable regions was decreased. Although, desert areas were increased. The results showed that steppe rangeland, agriculture lands, semi steppe rangeland and desert range land had decreased and mix of desert and bare land and salt lands had increased during 1999 to 2009. Li *et al*. (2013) studied desertification of rangelands using Landsat images in Ningxia, China during the years 1993 to 2011. They showed that a 60 percent decrease in desert area happened due to implementation of the law of Chinese government based on rangeland protection and prohibition of grazing in the region in 2003.

The expansion of the desert, which has been accompanied by exploitation of groundwater resources, as well as the misuse of agricultural land in recent decades will, in the long run, lead to decrease agricultural productions. Other studies also reported that severe drought and desertification could reduce vegetation and soil by water and wind erosion resulting in reduction of agricultural productivity (Whiteford, 2002; Ranjpishe *et al*, 2018). This study aimed to assess direction of changes in desertification and land degradation process in the Semnan County using remote sensing and meteorological indices.

2. Materials and Methods

2.1. Study area

Semnan County with an area of 11,018 square kilometers is located south of the Alborz Mountains and north of the Dasht-e-Kavir Desert. Semnan County lies between 35° 58′ to 34° 14′ N latitude, and 53° 18′ to 54° 11′ E longitude, and the elevation varies from 645 to 2857 m above mean sea level. The area has arid and semi-arid climate with hot summers and medium winters in foothills and cold in mountainous area, Shahmirzad, north of Semnan. The mean long-term maximum temperature varies from 8.4°C in January to 37.8°C in July while the minimum temperature varies from -12.8°C in January to 16.8°C in July. Annual average rainfall is about 141.7 mm. It is covered by sand and pebbles in most parts with limited vegetation (Kianian, 2014). In recent years due to overexploitation of groundwater resources many of villages are abandoned (Fig. 1).

2.2. Data and Indices

2.2.1. Meteorological Data and indices

Monthly precipitation was used to calculate a 12-month SPI (Standardized Precipitation Index). The SPI is on the bases of fitting a gamma probability density function to a given frequency distribution of precipitation totals for a weather station (Edwards and McKee, 1997; Guttman, 1998, 1999; Zarei *et al.*, 2013). SPI classes used for the present study are shown in table 1.

2.2.2. Satellite Data and indices

The Landsat Thematic Mapper (TM) sensor used for digital image processing (Table 2). Since the most vegetation cover takes place in April month, satellite data of the study area were collected in this month (Arastoo, 2015).

In addition, average monthly temperature and precipitation and average monthly total sunshine hours show that April month has favorable climatic conditions for vegetation to grow up in the area (Figs. 2, 3 & 4). NDVI is a vegetative indicator used for measuring pastures' capacity, this index was first used by Rouse *et al* (1973).

Table1. Classification of SPI drought conditions*

SPI Values	≥ 2.0	1.5 to 1.99	1.0 to 1.49	-0.99 to 0.99	-1.0 to -1.49	-1.5 to -1.99	≤ -2.0
Drought Conditions	Extremely wet	Very wet	Moderately wet	Near normal	Moderately dry	Very dry	Extremely dry

*(McKee *et al.*, 1993)

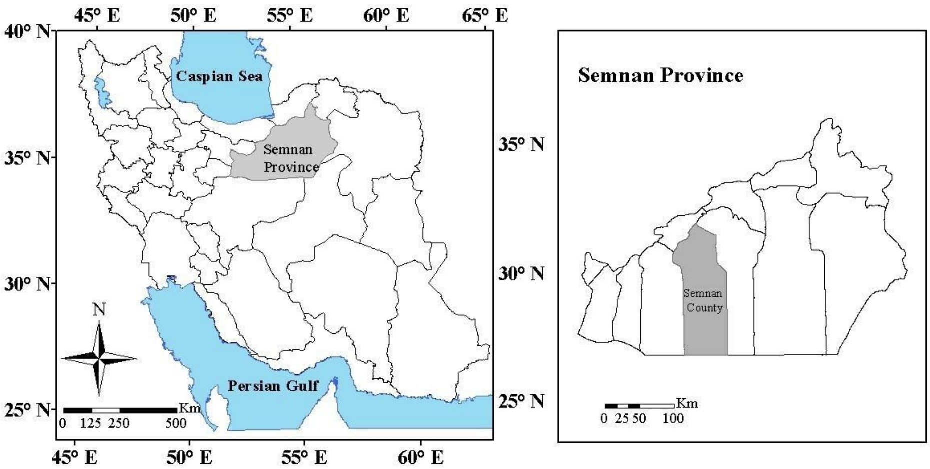

Fig. 1. Semnan County

Table 2. Satellite data used for digital image processing for selected years

Date	Location (Path/Row No.)
27 April 1987	163/35 & 163/36
19 April 1990	163/35 & 163/36
25 April 1998	163/35 & 163/36
17 April 2001	163/35 & 163/36
7 April 2009	163/35 & 163/36
13 April 2011	163/35 & 163/36

In general, healthy vegetation absorbs most of the visible light that it receives and reflects a large portion of infrared light, while unhealthy vegetation reflects most of the visible light that it receives and more infrared light. On the other hand, bare soil reflects both the visible and the infrared light in a balanced manner (Holme *et al.*, 1987; Hereher *et al.*, 2012). Theoretically, the NDVI index value is a ratio in the range of -1 to

+1 (Lillesand and Kiefer, 2004). Mathematically, it can be expressed as:

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad (1)$$

Where: NIR: Near Infrared Red reflectance
RED: Red reflectance
A typical NDVI values shows in table 3.

Table 3. Typical NDVI values for various cover types*

Cover Type	Red	NIR	NDVI
Dense Vegetation	0.100	0.500	0.700
Dry Bare Soil	0.269	0.283	0.025
Clouds	0.227	0.228	0.002
Snow and ice	0.375	0.342	-0.046
Water	0.022	0.013	-0.257

*Holben, 1986

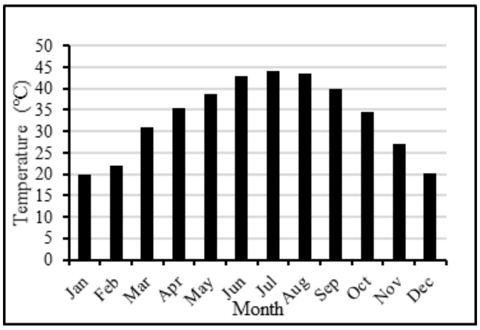

Fig. 2. Average long-term monthly maximum temperature

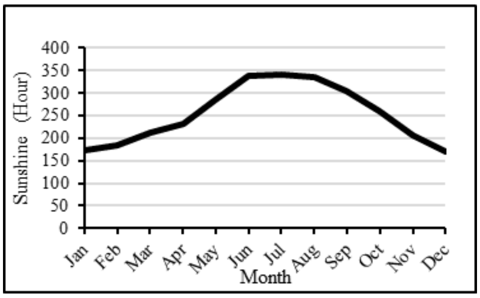

Fig.3. Average long-term monthly sunshine hours

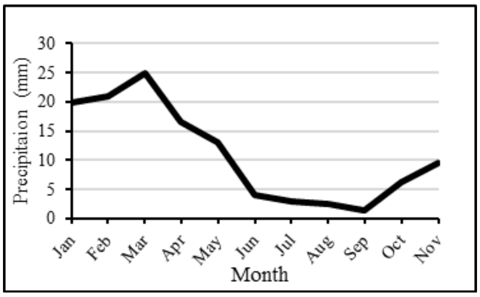

Fig. 4. Average long-term monthly precipitation

2.3. Image Processing and Classification

Land use/land cover classification plan proposed by National Remote Sensing Agency Hyderabad (NRSA, 1989) was taken on for land use/cover mapping. Determining whether or not desertification has been occurred in the area, satellite image processing and spatial analysis were carried out using ENVI5.4, and Arc/GIS10.3. Images of TM sensor for April month were used for the three years, *viz.*, 1987, 1998, and 2011. Five major categories were identified at level-I and they were subdivided into 11 categories including, 1. residential areas (residential and industrial), 2. vegetation (shrub land, cultivated land, productive and non-productive trees), 3. bare and rocky areas (moorland, mountains and bare ground), 4. salt lands and 5. sand areas (sand and clay).

Supervised classification and maximum likelihood methods have been used for land use/land cover classification and visual interpretation used for change detection. Ground Truth (GT) were implemented to evaluate the accuracy of land use/land cover classification (Bazgeer *et al.*, 2008; Wijitkosum, 2016). Flowchart of the research methodology for land use/land cover change analysis is shown in fig. 2. The areal extent of each land use/land cover classes were computed for the years 1987, 1998, and 2011.

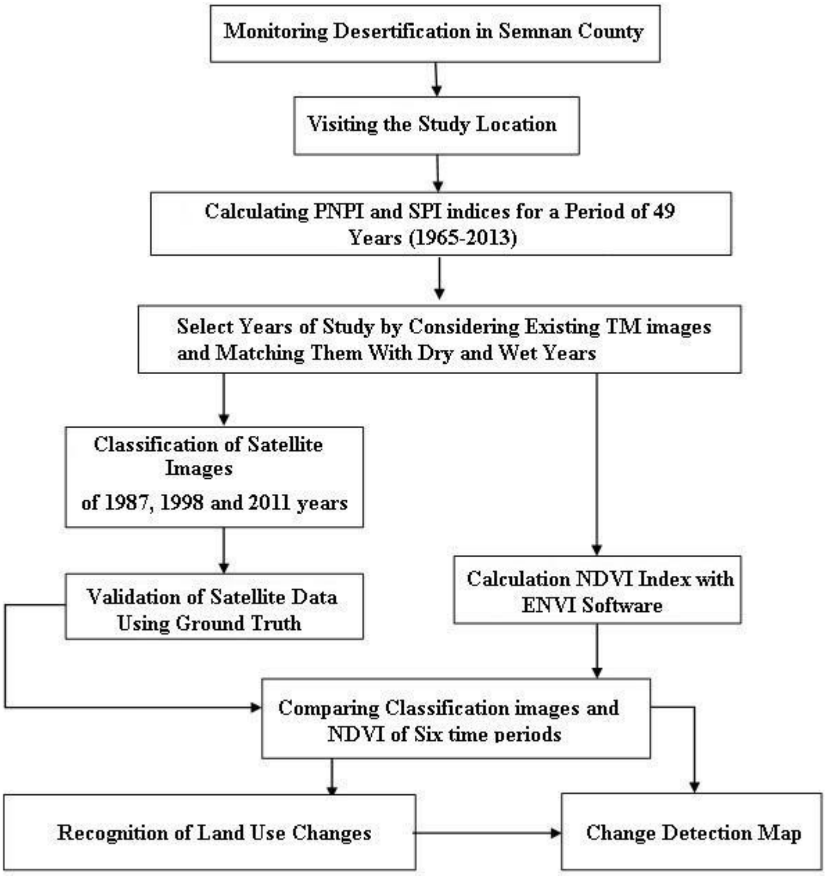

Fig. 5. The flowchart of research methodology

3. Results and Discussion

3.1. *Land use/land cover Change detection*

Table 4 shows the yearly SPI values and drought conditions from 1987 to 2012. No significant trend was detected in frequency and severity of SPI in the region. Nonetheless, it revealed that the study area was exposed to extremely drought conditions in 1996 and 2007 and severely dry conditions in 1989. The results showed that in most years the situations of near normal conditions were occurred. The United Nations (United Nations, 2001) reported that the country experienced drought from 1999 to 2001 which is in conflict with our results. Although, Zarei *et al.*, (2003) found that a wet conditions happened in 2005 which is in agreement with our study results. These differences could be partly due to the climate conditions of Semnan which has a dry climate type, and partly because it is not reasonable to compare the results of two studies with different spatial scales, i.e., Semnan County with Iran (Leelaruban, 2016). He found out the occurrence of drought could more and more unlikely as the spatial scales decreases due to more homogenous hydrological conditions allowing sudden variations of the area of certain drought intensity. Table 5 indicates land use/land cover changes from 1987 to 1998 (during 11 years) in different classes and extent of each change in each category. Although sand and clay class have been reduced by 755.38 square kilometers, bare and rocky land and salt land have been increased by 358.79 and 348.24 square kilometers, respectively. The total vegetation and residential categories did not change much over 11 years (1.85 and 13.24 square kilometers, respectively). From 1998 to 2011 sand and clay and bare and rocky areas have been decreased by 154.12 and 1000.42 square kilometers, respectively. It should be mentioned that 398.01 out of 1000.42 square kilometers have been covered with clouds in satellite images which removed from calculations. The salt land covered 1362.73 square kilometers in 1998 which rose to 2084.30 square kilometers in 2011 (721.57 square kilometers increased during 13 years). During 1987-2011 period sand and clay region and also bare and rocky region have been reduced by 909.5 and 644.63 square kilometers, respectively, in the whole area (table 5). However, salt lands significantly increased by 1069.81 square kilometers. Therefore, 1069 square kilometers of the land has been covered by salt in the Semnan County which happened within 24 years (approximately a quarter of one century). Fig. 6 shows land use/land cover change from 1987 to 2011. It is revealed from the map that desertification is extended into the east, center and south of the Semnan County which is faster than other directions. In addition, salt land is being expanded almost in the study area which is a warning signal for local governor.

Table 4. Yearly SPI values and drought conditions

Year	Precipitation (mm)	SPI	Drought Condition Severity
1987	189.8	0.4	NN*
1988	120.2	-0.8	NN
1989	86.8	-1.6	SD
1990	178.4	0.3	NN
1991	145.5	-0.3	NN
1992	132.8	-0.6	NN
1993	100.0	-1.3	MD
1994	116.6	-0.9	NN
1995	253.3	1.3	MW
1996	51.6	-2.8	ED
1997	165.9	0.1	NN
1998	118.7	-0.9	NN
1999	96.0	-1.4	MD
2000	122.7	-0.8	NN
2001	157.2	-0.1	NN
2002	175.2	0.2	NN
2003	167.8	0.1	NN
2004	150.0	-0.2	NN
2005	158.3	-0.1	NN
2006	260.4	1.3	MW
2007	68.6	-2.2	ED
2008	128.0	-0.7	NN
2009	102.2	-1.2	MD
2010	114.6	-1.0	NN
2011	177.1	0.3	NN
2012	107.3	-1.1	MD

* MD= Moderately Dry, ED= Extremely Dry, MW= Moderately Wet, NN= Near Normal, SD=Severely Dry

3.2. NDVI changes during study period

Similar to SPI, a time-series analysis of NDVI was done to detect changes on land cover over the study area. The results revealed that a non-significant relation found between NDVI and SPI. It could be due to difference in temporal scales and nature of data of both indices. Fig.7 shows NDVI changes in Semnan County during 1987, 1990, 1998, 2001, 2009 and 2011. As the study area is located in arid and semi-arid regions, the values of NDVI were mostly near zero and negative during April month, indicating low vegetation cover. The NDVI average reduced intensively between 1987 and 1998 period as compared with 1998 and 2011 years showing a significant desertification process in the former period. Shamsipour *et al.*, (2008) reported that the NDVI that tended toward 0 resulting from a bare soil condition. The results revealed that as time went on, NDVI values decreased from 1987 to 2011 resulted from degradation of vegetation cover. In addition, the conversion of barren into the salty land (saline soil) was quite obvious (Fig. 6). We checked the study site to make sure that our results were as reliable as possible and discuss with local communities (farmers, animal husbandmen and governor's employees). It was found that the desertification process was made progress in direction of east and southeast of Semnan County which was in agreement with NDVI maps (Fig. 7).

Table 5. Land use/land cover changes between 1987, 1998 and 2011 in Semnan County

Land use	1987	1998	2011	Land use Changes		
	Area (Km^2)			1987-1998	1998-2011	1987-2011
				Area (Km^2)		
Sand & Clay	6375.44	5620.06	5465.94	-755.38	-154.12	-909.50
Bare & Rocky	3573.83	3932.62	2929.20	358.79	-1000.42	-644.63
Salt lands	1014.49	1362.73	2084.30	348.24	721.57	1069.81
Vegetation	49.45	47.60	66.54	-1.85	18.94	17.09
Residential	4.92	18.16	37.18	13.24	19.02	32.26
Cloud	0.00	36.96	434.97	36.96	398.01	434.97
Sum	11018.13	11018.13	11018.13	0.00	0.00	0.00

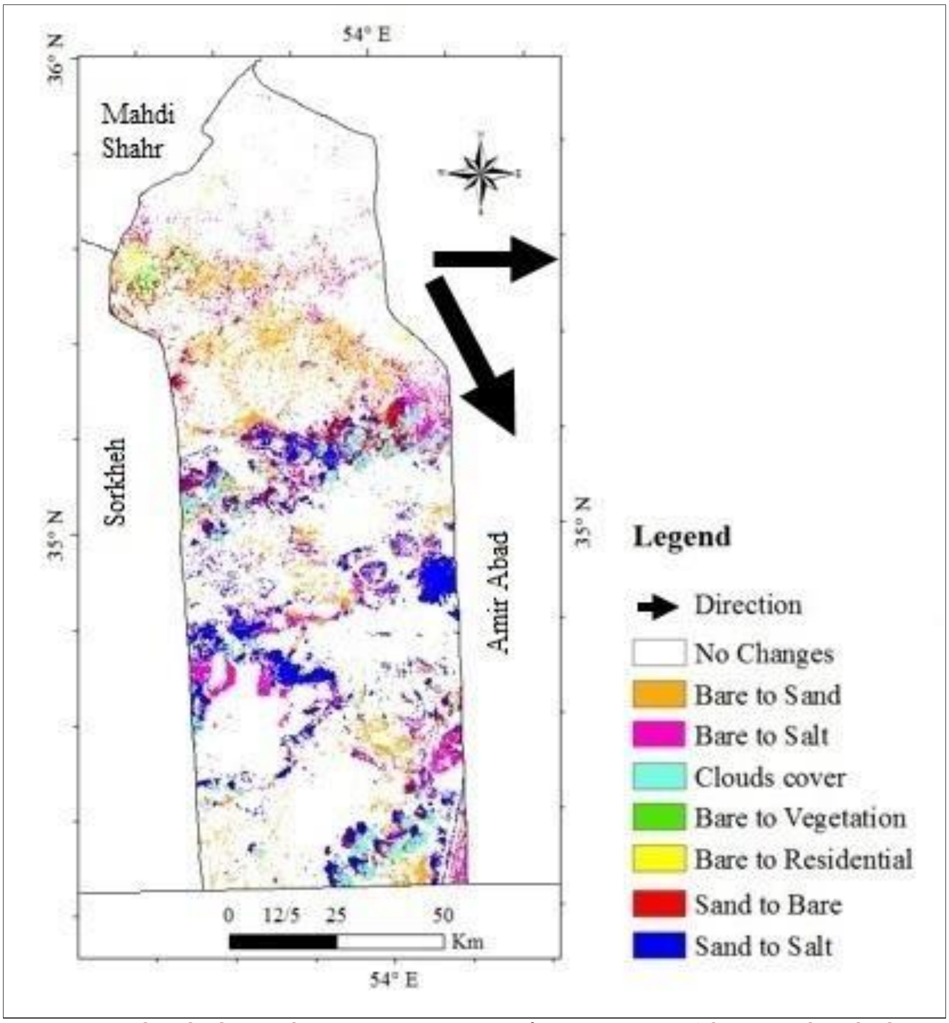

Fig. 6. Land use/land cover changes in Semnan County, from 1987 to 2011 (The arrows show the direction of desertification; the thickness of the arrows indicates the severity of desertification.)

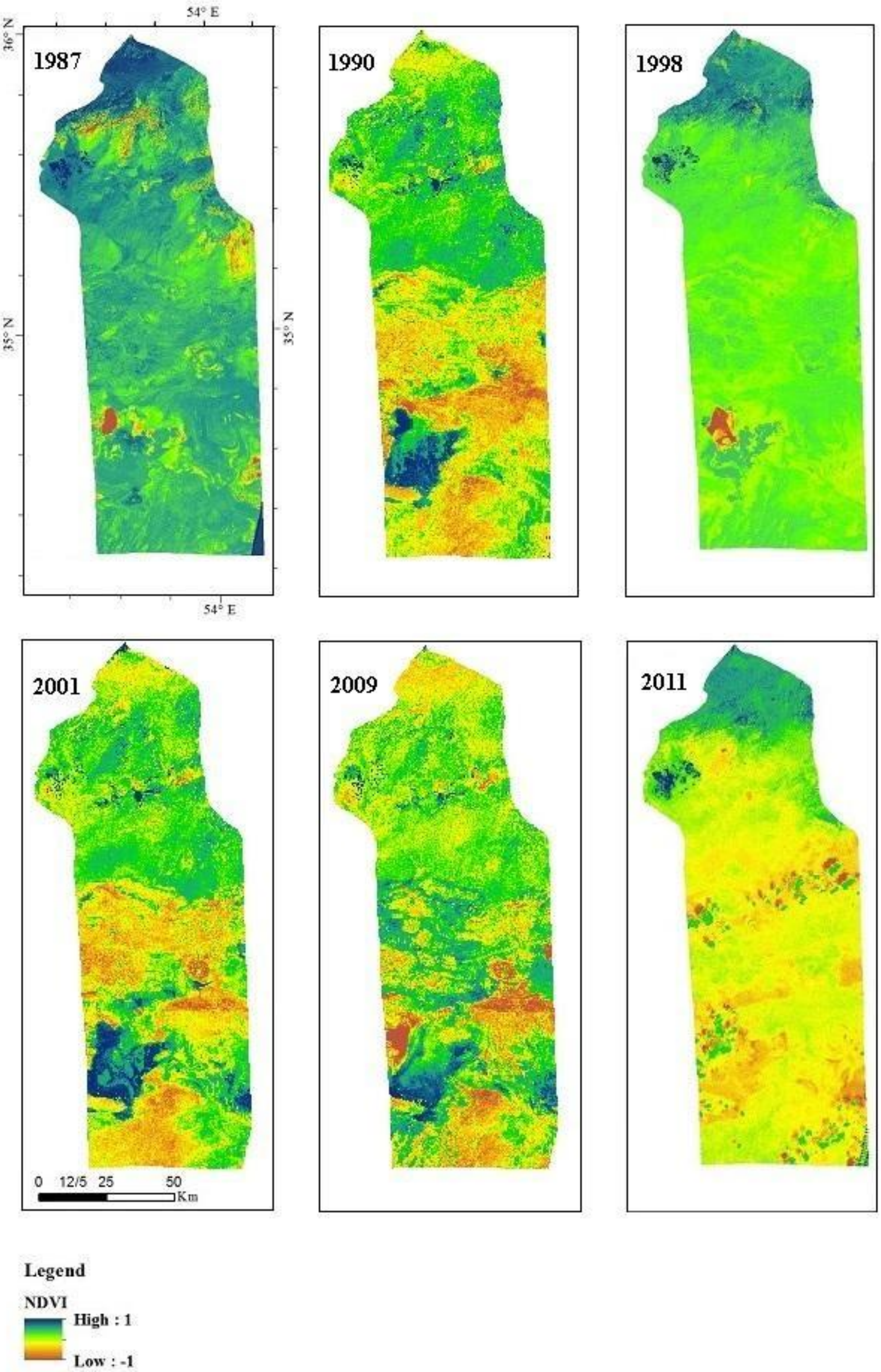

Fig. 7. NDVI changes in Semnan County during 1987, 1990, 1998, 2001, 2009 and 2011

In addition to assess variations of precipitation, the other climate factors such as evaporation should be analyzed for desertification process (Kardavani, 2007; Amiraslani and Dragovich, 2012). Therefore, the yearly anomaly of sunshine hours, evaporation, precipitation and water-level changes in aquifers were assessed during 1987-2011 (Figs. 8-11). It is obvious from the figures that the sunshine hours and evaporation increased in recent years and precipitation decreased in most of the years. Besides, the average cumulative water-level changes in aquifers showed a decreasing trend in the study area. Karmakar *et al.*, (2016) reported that high evaporation together with low precipitation resulted in vegetation cover reduction and hence soil degradation. This would lead to salinization. Similarly, in the study area, expansion of salt lands occurred particularly in east and southeast direction (Fig. 6). This change could in turn result in partly due to the changes in the socio-economic conditions and excessive exploitation of groundwater resources (Amiraslani and Dragivich, 2012; Anvarifar *et al*, 2013; Arami and Ownagh, 2017). According to a study carried out in Semnan province (Bayat and Hashemi, 2014), the rate of soil erosion in Semnan province was 2 ton/ha/year due to reduction of vegetation cover which prove the results of our study that desertification was occurred at a rapid rate, especially in the east and southeast directions in the study area.

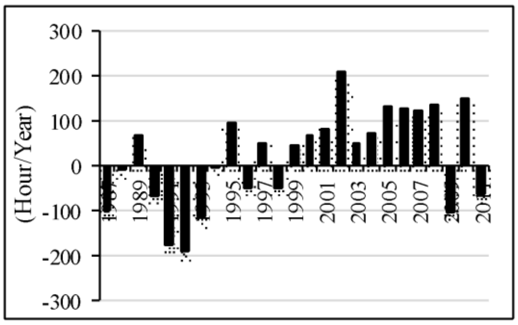

Fig. 8. Yearly anomaly of sunshine hours in Semnan County; Source: Iran Meteorological Organization (2016)

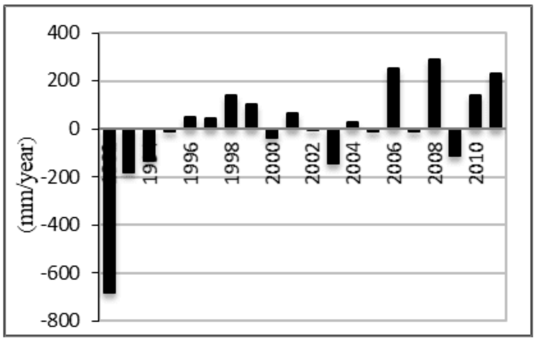

Fig. 9. Yearly anomaly of evaporation in Semnan County; Source: Iran Meteorological Organization (2016)

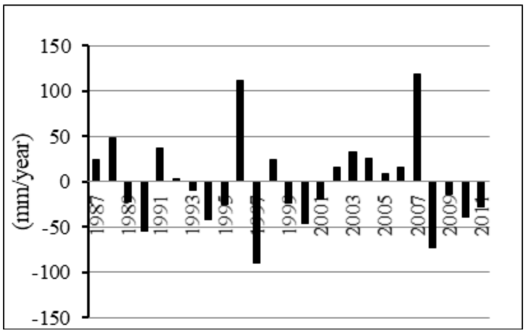

Fig. 10. Yearly anomaly of precipitation in Semnan County; Source: Iran Meteorological Organization (2016)

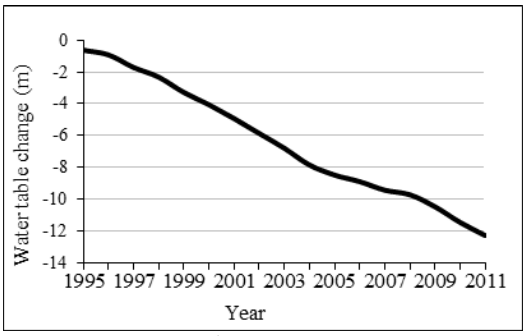

Fig. 11. Average cumulative water- level changes in aquifer in Semnan County; Source: Regional Water Company of Semnan (2017)

4. Conclusion

According to the April NDVI time series of 1987, 1990, 1998, 2001, 2009 and 2011, the results indicated that the reduction of the NDVI values was consistent with the changes in land use/land cover in the study areas. This progress was taken place in some areas with the development of bare soil to salt land, and in some areas with the expansion of sand land, particularly from 1987 to 1998. Moreover, the results revealed that besides using SPI for drought monitoring, the meteorological variables such as temperature, sunshine hours and evaporation could improve the accuracy of interpretation of the results. In addition to, our results showed that the normalized difference vegetation index (NDVI) obtained by remote sensing could widely used to monitor desertification change detection, which is in good agreement with those obtained from Li *et al.*, (2013); Zarei *et al.*, (2013); Gedif, (2014); Kundu *et al.*, (2015). In conclusion, this research found the study area is sensitive to soil erosion and the governor should plan the programs to control soil erosion and land degradation by enforcing best management practices such as cover crop.

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