DESERT

DESERT
Online at http://jdesert.ut.ac.ir

DESERT 13 (2008) 105-115

An analysis of drought events for central plains of Iran through an employment of NOAA-AVHRR data

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Received 29 May 2007; Received in revised form 29 September 2007; Accepted 22 October 2007

Abstract

Drought is a major problematic phenomenon for the mostly semi-arid country of Iran. The north central regions of Iran (north of Esfahan and Ghom province) have suffered from severe droughts several times during the last three decades. The frequent occurrence of drought in these regions is due to low and inconsistent precipitation, abnormally high temperatures, increases in surface albedo and evapotranspiration; especially during spring. The surface characteristics of Kashan and Ghom regions consist of salty flats and sandy hills covered by sparse vegetation. The average elevation of the area is 1987 mASL. In the present work, NOAA-AVHRR data have been employed to assess vegetation indices and environmental conditions in the study region for the years 1998 – 2004; which are then compared to actual ground data such as rainfall, temperature and relative humidity for a detailed drought analysis. Spatial and temporal variations of meteorological droughts in Kashan have been analyzed using Standardized Precipitation Index (SPI) at annual and seasonal scales, and have been generated through GIS based interpolation. Vegetative and thermal drought indices have been calculated using NDVI, VCI, and TCI values derived from NOAA-AVHRR data. Results from applying remotely sensed data show that this area is generally of low vegetation index values. The artificial forests and farmlands at the foothills of the mountains northwest of Kashan region showed relatively high vegetation index values. TCI and VCI generally show a good relationship with meteorological observations. According to the output of utilization NDVI and VCI, 2000 and 2001 years were characteristic of drought conditions, while 2002 and 2004 did non represent drought years. Since TCI index is completely dependent on surface temperature, the combined analysis of the May and April results were influenced by the low land surface temperatures experienced in April, and therefore it was very different from the other indices i.e. NDVI and VCI. Therefore thermal IR channels can be employed used to monitor drought conditions in the semi-arid and arid regions of Iran to assess these regions, environmental conditions.

Keywords: Drought indices; Remotely Sensed Data; AVHRR-NOAA; NDVI; Central plains of Iran

1. Introduction

Drought is a natural hazardous phenomenon that significantly impacts economic, agricultural, environmental, as well as social aspects in an area (Jeyaseelan, 2005). Drought is one of the major environmental disasters in plateau of Iran. In recent years, frequent and severe drought incurred to the environment and agriculture of some provinces have been extensive, and the death toll of livestock and wildlife unprecedented. Weather data often come from a very sparse meteorological network, incomplete and/or not always available in proper time to enable relatively accurate and timely large-scale drought detection and monitoring. Therefore, remotely sensed data has often been employed to investigate spatial and temporal patterns of drought. Data obtained from the Advanced Very High Resolution Radiometer (AVHRR) sensor on board the

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NOAA polar-orbiting satellites have been studied as a tool for drought monitoring and climate impact assessment in northwest of great Kavir (Iranian desert).

For countries situated in arid regions, such as Iran, monitoring drought has become increasingly important as a tool for environmental management. Especially since future climate prediction scenarios show that South Asia and Middle East will experience more severe and prolonged droughts as a result of the increase in greenhouse gases in the atmosphere (IPCC, FAR Fourth Assessment Report). In the past decade, Advanced Very High Resolution Radiometer (AVHRR) derived indices have been developed which can aid in detection and monitoring of drought conditions (Krishna, *et. al.* 1990) (Table 1 provides their mathematical definition). Techniques for mapping vegetation cover and classification have recently been improved. Kogan (1995) has shown that Temperature Condition Index (TCI), which is obtained from AVHRR thermal bands, can be a good indicator for vegetation stress caused by temperature and moisture availability. In conjunction with Vegetation Condition Index (VCI), TCI has been applied to drought monitoring in countries such as India (Singh et al. 2003). Kogan (1995) also proposed Vegetation Health Index (VHI) which has been used for drought detection, determining drought severity and warning system. Karnieli et al. (2006) applied VHI to study the drought in Mongolia.

The values of the normalized difference vegetation index (NDVI), vegetation condition index (VCI) and temperature condition index (TCI), and vegetation health index (VHI) extracted from satellite sensor data acquired by the National Oceanic & Atmospheric Administration Advanced Very High Resolution Radiometer (NOAA-AVHRR) were used in this study for drought detection in Kashan Region situated in the arid central plains of Iran. The above said index values decrease during the drought period. This effect, which is clearly visible in the drought suffering regions, was associated with vegetation moisture and heat stress (Cihlar et al. 1991, Cesari et al.2002, Ichii et al.2002). In addition to the above said indices, Land Surface Temperature (LST) and Land Surface Moisture (LSM) may be estimated using thermal infrared data and a combination of visible - thermal infrared bands as acquired through AVHRR and used in this study.

Kashan is not only an important agricultural zone in Iran, but it also contains a variety of surface cover ranging from high albedo surface of a salt lake to agricultural land zones. Since 2000, like many other places in Central and Southwest Asia, as well as most parts of Iran it has experienced a three-year period of drought, the worst in recent history. Some regions - such as the Sistan Basin on the border with Afghanistan - still have not recovered. Remote sensing studies focused on Iran are rare, yet could be used to monitor the effects and extent of drought. Toomanian et al. (2004) used AVHRR (Normalised Difference Vegetation Index; NDVI) for an application to irrigation in Esfahan region (Figure 1). Aminzadeh and Samani (2006) provide an interesting example of the nexus between archaeology and remote sensing by using high-resolution LANDSAT imagery to identify boundaries of Persopolis, the ancient capital of Persia. AlaviPanah, S.K. (2004, 2006) has written books about Application of Visible and Thermal remote sensing in earth sciences. There are also varieties of other studies, but mostly published in Farsi (the national language of Iran), some of which were as mentioned above.

The aim of this paper is to study the spatial and temporal patterns of drought events in the North-eastern fringes of the Central Plateau of Iran through remote sensing and in situ datasets. The temporal and spatial pattern of drought is determined thru GIS-based interpolation of Z-Normal index for annual and monthly timescales. NOAA-AVHRR dataset for years 1998 to 2004 were used for an analysis of the remotely sensed indices.

The Aims and objectives of this study are to:

- Compare AVHRR drought indices such as NDVI, VCI, TCI, and VHI with meteorological indicators (Z Square calculated from climate station data) for the period 1998 to 2004.
- To asses the utility of AVHRR data in this arid area, since studies in this context in arid zones are rare.
- To compare the agreement between NDVI, and VCI which are derived from reflective channels, with TCI and Land Surface Temperature (LST) derived from thermal IR channels. Sigh et al. 2003 found that VCI alone could not be used to predict droughts and TCI is also needed.

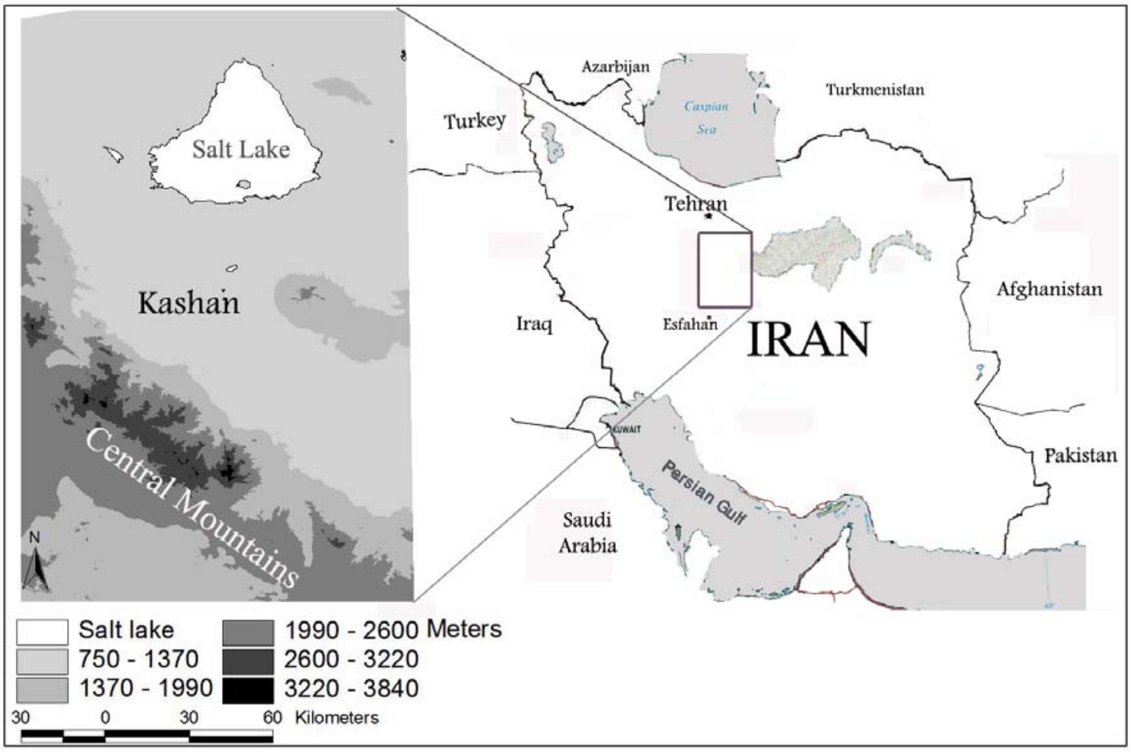

Fig. 1. Location of study area on Iran map

2. Study area

Kashan, the area of interest is situated to the north-west of the Iranian desert (Dasht-e-kavir; Figure 1). The area covers approximately 31,680 km^2, spanning 33 - 35°N and 51 - 52° 30'E. The region is arid with an annual average precipitation of 138 mm since it falls under the rain shadow caused by Zagros Mountain Ranges, a dominant feature of West Iran. Most precipitation falls in winter when a series of low-pressure synoptic scale depressions - originating from the Mediterranean - track over central Iran. The average topographical height of the area is about 1987 mASL, where thin vegetation covers sand dunes and bare lands. Climatologically the aridity is probably due to the fact this area falls under the subtropical high-pressure belt. As a consequence, clear (cloudless) skies are common and sunshine hours are approximately 2860 per year.

3. Materials and methods

The methodology is based on the analysis of mutli-year sets of daily AVHRR data, daily meteorological data and various surface characteristics held as coverages in GIS (i.e. DEM, soil types, and land cover types).

The indices derived for this work have been prepared from 1.1 km^2 resolution AVHRR images obtained from NOAA-14 and 16, with overpasses between 8:30 a.m. and 11:00 a.m. local time. We obtained 121 images from May 1998 till 2004 (data for May 2000 was unavailable, therefore for this year we used April dataset). In addition, for 2004 we also have the April dataset. The May period was chosen since in this region maximum vegetation density occurs at this time. After May, vegetation cover is reduced dramatically, because the phenology for vegetation here is short. This is a particular adaptive mechanism of vegetation in this area since the rainy season is very short. For each image, pre-processing included geometric, radiometric, and atmospheric correction using ERDAS 8.7 and ILWIS 3.2 software packages.

The methodology of remotely sensed data on the analysis of vegetation and land surface characteristics used some physical and drought indices such; Normalised Difference Vegetation index (NDVI), from brightness temperatures and is converted into Vegetation Condition Index (VCI), and Temperature Condition Index (TCI). Vegetation Health index (VHI), (Table 1).

Table 1- NOAA-AVHRR images-derived and meteorological-measured drought-indices

Drought indices	Formula	Source and reference
(1) Normalized Difference Vegetation Index (NDVI)	$NDVI_{ijk} = \frac{(NIR_{ijk} - R_{ijk})}{(NIR_{ijk} + R_{ijk})}$	Jordan, 1969; Deering, 1978; Tucker, 1979; Tucker & Choudhury, 1987; Ji & Piters, 2003
(2) Vegetation Condition Index (VCI)	$VCI_{ijk} = \frac{(NDVI_{ijk} - NDVI_{i,\min})}{(NDVI_{i,\max} - NDVI_{i,\min})}$	Kogan, 1990, 1995, 1997, 2000
(3) Temperature Condition Index (TCI)	$TCI_{ijk} = \frac{(BT_{i,\max} - BT_{ijk})}{(BT_{i,\max} - BT_{i,\min})}$	Kogan, 1995, 1997, 2000
(4) Vegetation Health Index (VHI)	$VHI_{ijk} = 0.5 * VCI_{ijk} + 0.5 * TCI_{ijk}$	Kogan, 1997, 2000, Kogan et al., 2000
(5) Land Surface Temperature (LST)	$T_S = BT_4 + A(BT_4 - BT_5) + B$	Price (1984)
(5) Land Surface Moisture (LSM)	$LSM = 25.86 - 7.901 \times (BT4 - BT5) + 0.46 \times LST - 1.21 \times Albedo$	Seyedan (2003)

NIRijk and Rijk—reflectance values at the near-infrared (channel 2) and red (channel 1) wavelengths of NOAA–AVHRR, respectively, for pixel i during month j for year k.
Note that j can also be referred to 8-day (e.g. MODIS data), 10-day (e.g. PAL AVHRR), 14-day (1 km AVHRR), 16-day (1 km MODIS), depending on the time intervals of data sets.
NDVIijk — monthly NDVI for pixel i in month j for year k.
NDVIij — multiyear average NDVI for pixel i in month j.
NDVIi,min and NDVIi,max — multiyear minimum and maximum NDVI, respectively, for pixel i.
BTijk — brightness temperature at channel 4 for pixel i in month j for year k.
BTi,min and BTi,max — multiyear minimum and maximum brightness temperature, respectively, for pixel i.
Zijk — monthly moisture status for pixel i in month j for year k.
A=2.63 B=1.27

To take into account variation in atmospheric conditions, maximum value composite (MVC) of up to 14 days was constructed for NDVI and LST. The algorithm selected in this study for the estimation of LST using AVHRR thermal infrared (channels 4 and 5) data, is a global ‘Split Window’ algorithm developed by (Price, 1984). It requires the brightness temperatures in AVHRR channels 4 and 5, the mean emissivities and the spectral emissivity difference in these channels. Soil moisture was measured *in situ* from several locations in this region to estimate Land Surface Moisture (LSM) parameter (Seiedan 2001; Table 1). LSM is calculated from linear regression relationship between soil moisture, LST, albedo, and brightness temperatures. Process of the methodology has been shown at the follow flowchart (figure 2).
Consequently, Results of remotely sensed indices were numerically validated by in situ data of meteorological variables such as monthly average precipitation, Relative Humidity and air temperature.
To take meteorological conditions into consideration, a three-month Index of Z Square (Z) was calculated for March, April, and May for each year from 12 climate stations in the region according to McKee (1993) (Table 2). Z Square was determined for precipitation, temperature, and relative humidity. According to Li and Peters (2006), three-month Z square values should be used to take into account lag and cumulative effects of precipitation.

$$Z = \frac{X_i - \overline{X}}{S} \quad (1)$$

Where X_i is meteorological variable, $\overline{X}$ is its averaged value for three months, and S is standard deviation.

Table 2. Station locations

Station	Period	Latitude Longitude	Elevation (m)
Abyaneh	1978-2003	33° 34′ N 51° 35 ′ E	2234
Ardestan	1964-2000	33° 37′ N 52° 37′ E	1381
Ghom	1964-2004	34° 42′ N 51° 50′ E	877.4
Kashan	1951-2004	33° 59′ N 51° 27′ E	982.3
Natanz	1964-2000	33° 32′ N 56° 51′ E	1800

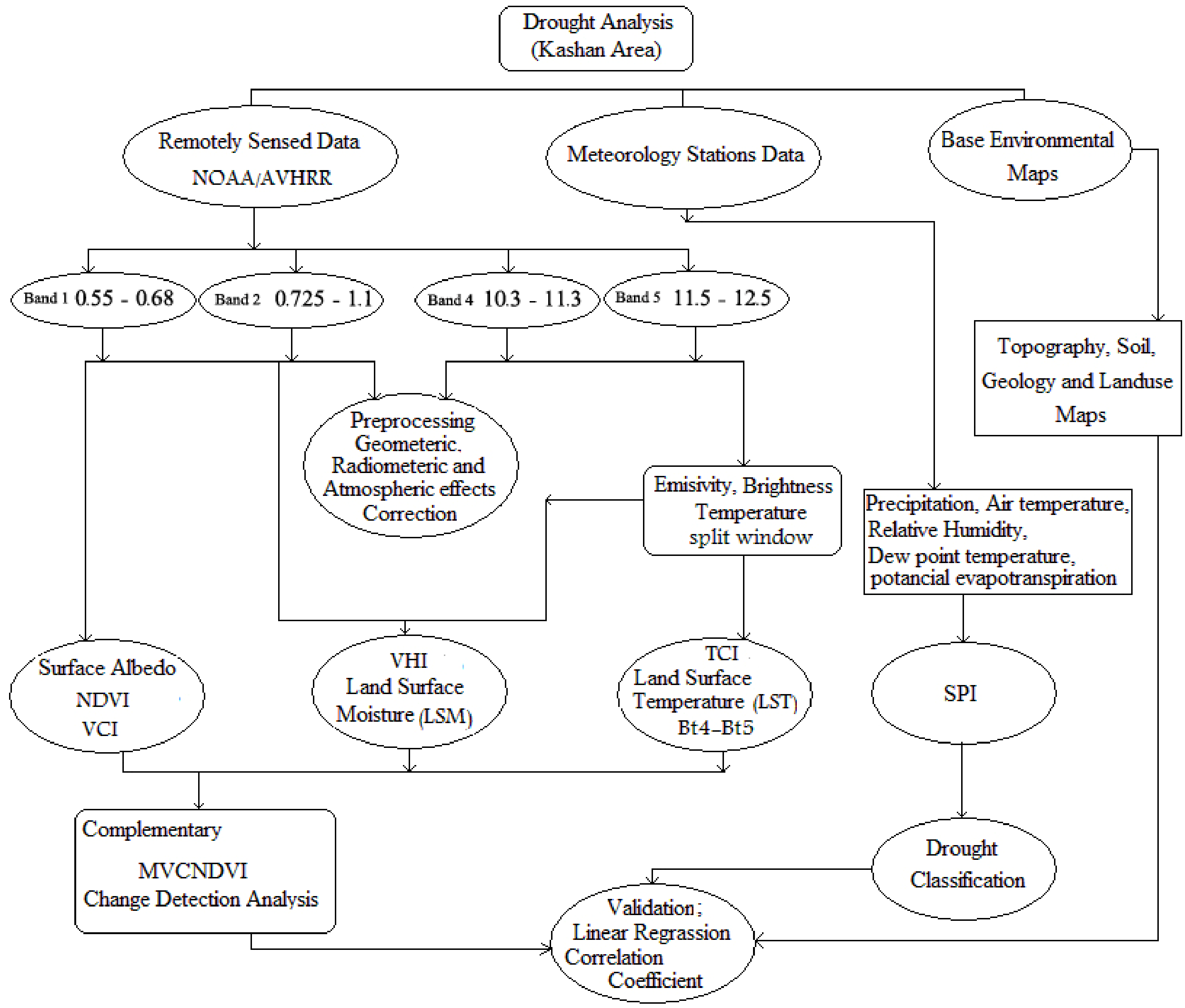

Fig. 2. Flowchart of methodology process

4. Results and discussion

The results show that NDVI, VCI, and oil moisture indicate 2000 and 2001 experiences drought and 2002, 2004 were wet years.

NDVI and TCI, these indices are being used for estimation of vegetation health and monitoring drought. The present study shows the application of vegetation and temperature condition indices for drought monitoring in Iran Ideally for such an analysis a longer dataset is required (20 years or more), but Space Agency of Iran has only catalogued AVHRR data since 1998. Figure 3 shows the time-series of Z square for the 5 stations in the Kashan Region while Table 2 itemises the location and elevation of each. SPI values for all stations show that in 2000 and 2001 the area experienced a severe drought, indeed most of Iran was under drought conditions in this period as mentioned above. Wet years were experienced for 2002, and 2004. For 1997 and 1998 the SPI values across the region are heterogeneous. The reason that 2002 shows such an excessive wet year is that in a 48 hour period there was intense precipitation event, Kashan station measured 124 mm for this single episode against a backdrop of 138 mm/year. Therefore we will consider 1999, 2002, 2004 as wet years, and 2000 and 2001 as drought years for comparison with AVHRR indices.

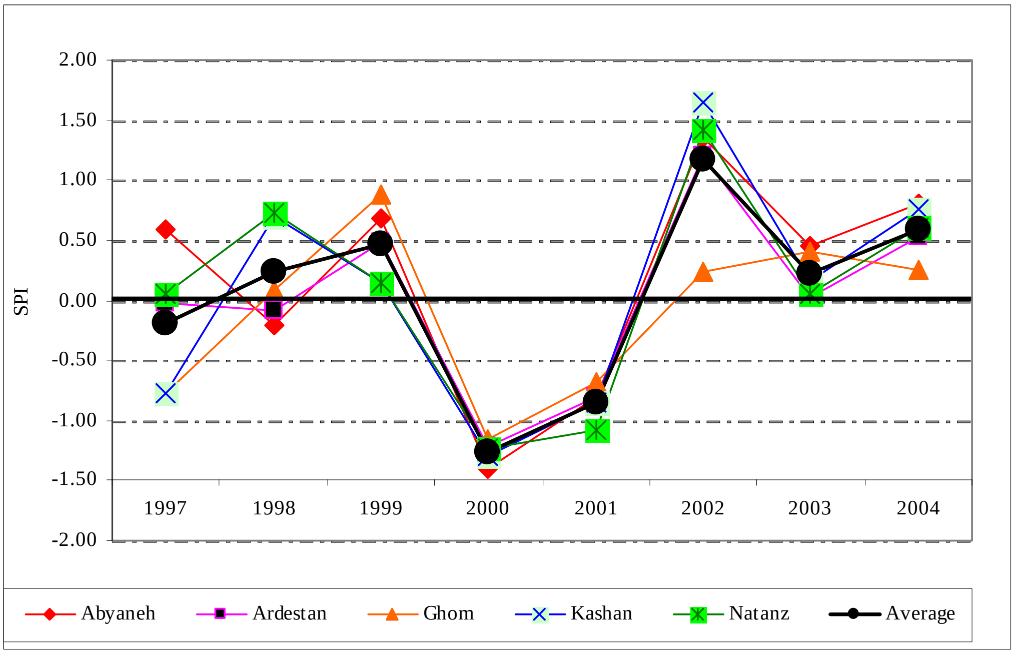

Fig. 3. Standardized precipitation index on Kashan area for climate stations

Figure 4 shows the spatial pattern for the maximum, minimum, and average values of NDVI, while Figure 5 reproduces the same data as box-and-whisker plots broken into monthly periods (including the standard deviation for NDVI). It is apparent from these figures that the Kashan area is extremely arid with very little vegetation cover. The maximum values which show the extent of the agricultural and pastoral land-cover, are mostly situated at the foothills of Central Mountain Ranges covering only a minor fraction of the total area (Figure 4a). The source of water here is from from Qanat and deep wells. Qanats are a system for directing snowmelt through underground channels (Lambton, 1978). However, in recent years water is mostly withdrawn from deep wells. The average values highlight the Salt Lake boundary with strong negative NDVI values (Figure 4b). Average NDVI for most of the area is close to zero showing the dominance of exposed soil (again, very little vegetation). Minimum values emphasize that the north-western fringe of the salt lake contained water at some time during this period (the salt lake is ephemeral and only has water in the spring). The dry sections of the lakebed consist of a 15-45m layer thick salt crust.

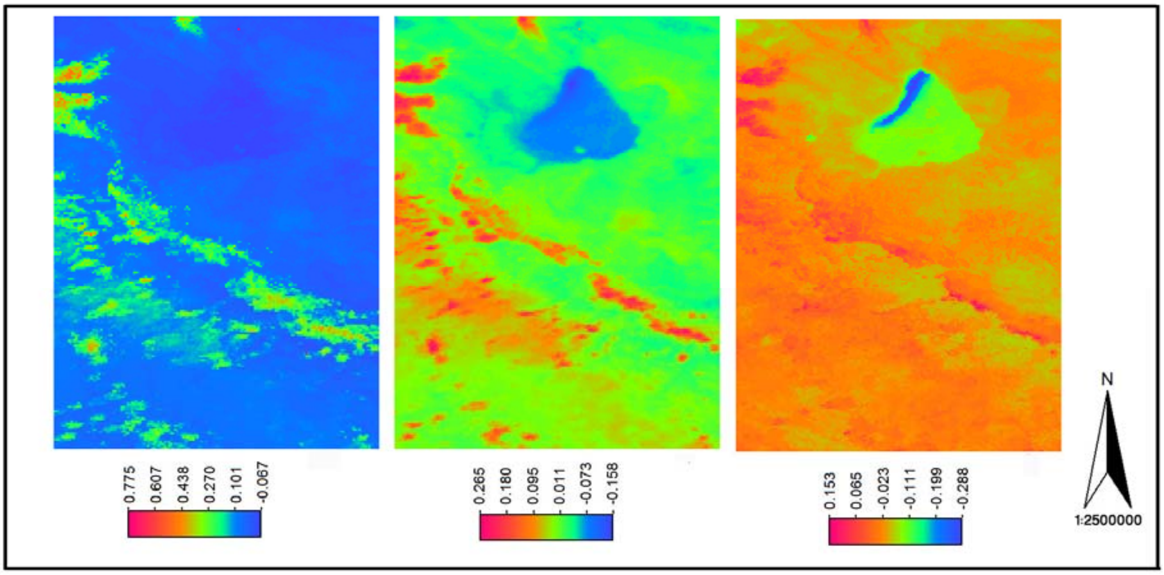

Fig. 4. Maximum, average, and minimum NDVI for the entire period

The aridity of the area is further highlighted by the negligible variation from zero in average NDVI from year to year (Figure 5). There is a significant difference between maximum and average values, in contrast with the difference between the average and minimum NDVI. The homogeneity in aridity of the region is also evident from the similarity between the standard deviations from year to year. For 2002 and 2003 the maximum NDVI is remarkable, but the average values are similar to those of the other periods. The reason for this could be the rainfall only causing the greening of agricultural lands as well as artificial forest areas, but made no difference in vegetation cover elsewhere. Another point to note in this figure is that there is very little difference between May and April NDVI; therefore they can be used interchangeably.

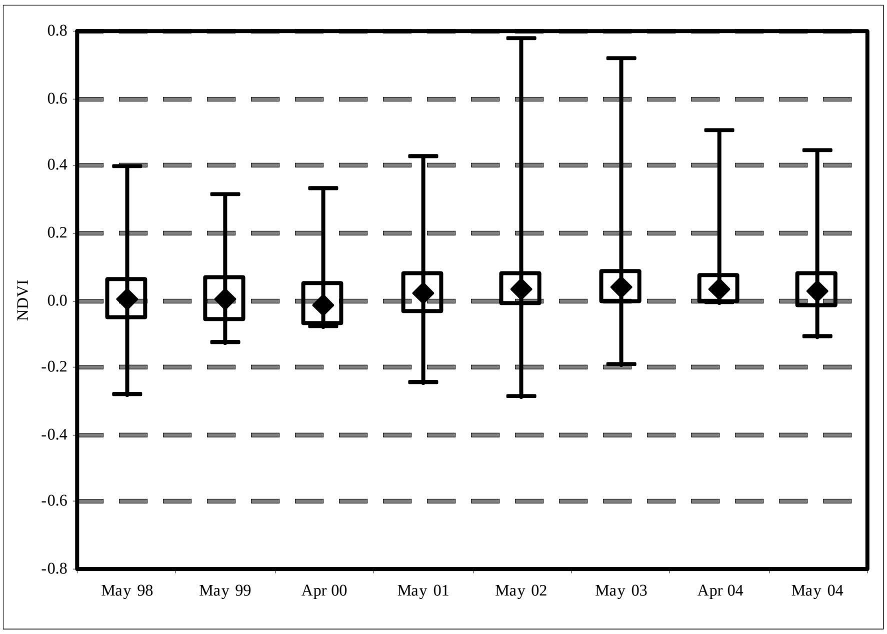

Fig. 5. NDVI for study area (1998 - 2004)

Figure 6 shows the VCI, TCI, LST, and LSM for each month. Low VCI values represent stressed vegetation conditions, with middle values representing fair and while high values representing optimum conditions (Figure 6a). VCI shows that vegetation was under stress for 1998, 1999, and 2000. From 2001 onwards VCI tends to increase, with optimal conditions in 2002 and 2003 – corresponding to wetter years. Although the three month average for precipitation was higher in 2004, as reflected in SPI values, VCI in 2003 is higher probably due to the fact that in that year the month of March was extremely wet. TCI values for April 2000 and 2004 are higher than those for other years since April is climactically cooler. TCI seems to be much more sensitive and more representative of environmental conditions than VCI. TCI shows that the worse thermal conditions existed in 2001. It is interesting to note that although VCI for 2002 shows good conditions, TCI is low. There is a significant variation in TCI between April and May due to warmer temperatures in May (Figure 6b). This variation is not evident in LST since desert surfaces are invariably warm during the day due to aridity and lack of vegetation (Figure 6c). LST minimums for April are lower as compared to May because the higher elevations are still covered with snow. As the snow melts the minimum LST increases by May. LSM is roughly an estimate of moisture availability at the surface and is employed as an additional analytical tool here. LSM values are generally below 50%, pointing towards the aridity of the region, and the inter-annual variability due to dry and a wet year is in agreement with LST and NDVI, the wet period in 2002 being highlighted here (Figure 6d).

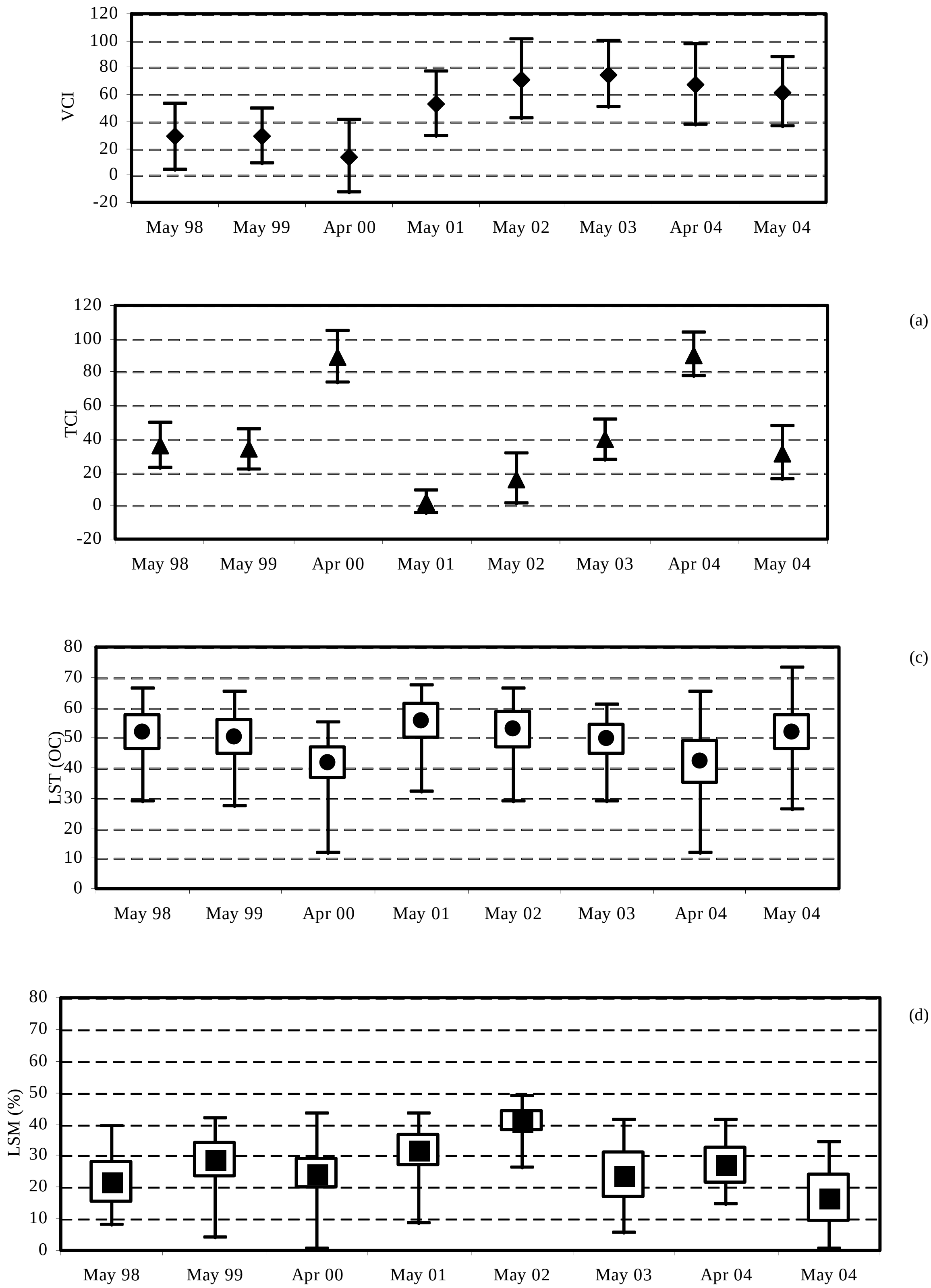

Fig. 6. Remotely sensed indices for study area (1998 - 2004)

Table 3 is indicative of the fact that NDVI and VCI are in a high correlation with relative humidity and temperature, but not with precipitation due to the inter-annual variability of precipitation and its sporadic nature. It is not clear why TCI and LST are not strongly correlated with meteorological parameters. In summary, indices derived from such reflective bands as NDVI and VCI seem to be more correlated with meteorological parameters than thermal bands derived indices like TCI and LST. Indices that use both reflective and thermal bands such as LSM and VHI do not seem to be a reliable measure of drought conditions.

Table 3. Correlation coefficient matrix between remotely sensed derived indices and meteorological parameters

Variables	LST	LSM	NDVI	VCI	Tci	VHI	Zrain	Ztemp	Zrh
LST	1.00								
LSM	0.23	1.00							
NDVI	0.22	0.17	1.00	…..					
VCI	0.24	0.24	0.99	1.00	…..				
Tci	-0.75	-0.59	-0.19	-0.25	1.00				
VHI	-0.53	-0.31	0.58	0.54	0.67	1.00	…..	…..	
Zrain	-0.03	-0.48	0.50	0.43	0.13	0.40	1.00		
Ztemp	-0.11	0.13	-0.86	-0.81	-0.12	-0.66	-0.72	1.00	…..
	0.35	-0.04	0.75	0.72	-0.27	0.26	0.83	-0.84	1.0

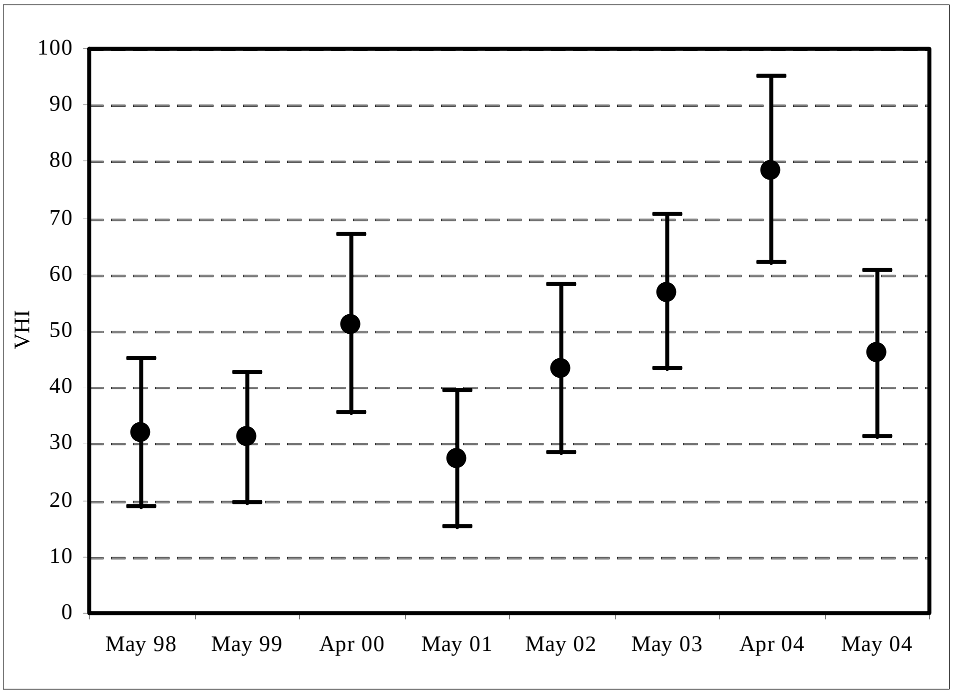

Fig. 7. Minimum, average, and maximum VHI

5. Conclusions

Results clearly indicate that temporal and spatial characteristics of drought in the study area can be detected, tracked, and mapped using AVHRR data. Based upon an analysis for Kashan area, this study shows that environmental conditions during several years can be practically used for an analysis of drought through remote sensing indices.

Based on the obtained results, a high difference between maximum and minimum NDVI values in wet years shows that there exists a more dominance of bare land (with no vegetation cover) as compared with a small irrigated farming area, and limited artificial woodlands. TCI Results reviews, show high flexibility in thermal bands as compared with visible data of surface temperature variations.

- It was shown that remote sensing data can be practically useful in analysis of drought events in the arid areas of Iran.
- Results indicate that thermal bands are of a higher sensitivity than the visible bands of land surface and air conditions in the area.
- Due to the sparse vegetation cover, the maximum NDVI values are more instructive in describing the drought conditions as compared with to average values, since most of the area is dry anyway.

- Best conditions were prevalent in May 2002 and 2003. Nevertheless, drought condition (in 2000. 2001) exerted the worst thermal stress.
- Based on validated analysis such vegetation indices as NDVI and VCI are in high correlation with Z square of average temperature and relative humidity. However, TCI and VHI do not exhibit any correlation with climate indices.

Despite the promising results found in this study, there is need to improve the quality of satellite data for operational applications. Satellite data is largely affected by various sources of error such as satellite changes, orbital drift, and sensor degradation, atmospheric perturbation due to aerosols and clouds, and surface non-uniformity change in equator crossing time during the satellite life span. It can, however, be concluded that when used together with climate stations data, AVHRR data from NOAA polar orbiting satellites can provide valuable information regarding the start of drought, development, and impacts on regional scale as well as on such arid zone scales as Kashan area.

Acknowledgment

The authors would like to thank and acknowledge the sincere help of the staff of Iran space agency, and state meteorological organization for provision of satellite images, and the needed data, as well as for their useful comments in the analysis of work in this research.

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