In: Wagner W., Székely, B. (eds.): ISPRS TC VII Symposium – 100 Years ISPRS, Vienna, Austria, July 5–7, 2010, IAPRS, Vol. XXXVIII, Part 7B

REMOTE SENSING FOR DROUGHT ASSESSMENT IN ARID REGIONS (A CASE STUDY OF CENTRAL PART OF IRAN, "SHIRKOOH-YAZD")

M. Ebrahimi [a], A. A. Matkan [a], R. Darvishzadeh [a]

[a] RS & GIS Department, Faculty of Earth Sciences, Shahid Beheshti University (SBU), Tehran, Iran- (mohsen_ebrahimi@hotmail.com; a-matkan@sbu.ac.ir; r_darvish@sbu.ac.ir)

Commission VII

KEY WORDS: Vegetation, Application, Monitoring, Precipitation, LANDSAT, Spectral

ABSTRACT:

Rainfall, soil moisture, increasing temperature and changes in vegetation cover are the most important parameters effecting drought. Therefore, analysis of vegetation fraction and soil spectral signature, especially in red and infra red bands, are essential in drought estimation using remote sensing. In this study, Modified Perpendicular Drought Index (MPDI), which uses Vegetation Fraction (VF) and Perpendicular Drought Index (PDI) (computed based on the amount of rainfall and the soil moisture) has been used for monitoring and drought assessment in arid regions in central part of Iran during a time interval of three years (1999-2002). To do so, ETM+ images of LANDSAT 7 for the years 1999 and 2002 and the rainfall statistics of 23 years have been used. Analysis of vegetation cover using NDVI, RVI, SAVI, MSAVI, SAVI2 and PVI indices demonstrated that in arid regions changes in vegetation cover were best mapped using SAVI2 index. Also, in comparison with PDI and VSWI indices, drought severeness was best demonstrated by MPDI index. Further, the results were analyzed and evaluated using Run-test model and metrological data of the existing stations in the region. The results of the study indicated that in the year 2002 although in comparison to year 1999, the amount of rainfall has been increased, vegetation fraction has been decreased and consequently, drought has been increased in the rangelands of the study area. This is due to the existence of a severe drought and decrease in seeding of rangeland vegetations in previous years (2000, and 2001).

1. INTRODUCTION

Drought is a severe dilemma which influences different aspects of mankind’s life. It can cause many economic and eco-environmental problems especially in the agriculture sector (Goddard 2003). In the last three decades, remote sensing has provided a useful tool for drought monitoring and a variety of remotely sensed drought indices based on vegetation indices, land surface temperature (LST), albedo, etc have been developed. Several drought indices have been proposed based on normalised different vegetation index (NDVI, Rouse et al., 1974) to monitor drought severity such as Anomaly Vegetation Index (AVI) and Vegetation Condition Index (VCI) (Chen 1994; Kogan 1995a), Vegetation Condition Albedo Drought Index (VCADI) (Ghulam et al., 2006), Temperature Drought Vegetation Index (TDVI) and Vegetation Temperature Condition index (VTCI) (Wang 2001; Sandholt 2002).
Since there is a lag-time between the drought occurrence and the change of NDVI, the indices which are based on NDVI may not be appropriate for the real time drought monitoring.
In addition, retrieval of the surface albedo and the LST contains uncertainties rooted in the atmospheric correction of satellite data, decomposition of mixed pixel information, BRDF modeling and the spectral remedy by a narrowband to broadband conversion (Zhao 2000; Pokrovsky 2002; Liang 2003). As a consequence, the final error associated with the extraction and quantification of drought information would be magnified.
In 2007 Ghulam et al., presented the Modified Perpendicular Drought Index (MPDI) as a real time index for drought monitoring based on vegetation fraction (estimated using NDVI) and Perpendicular Drought Index (PDI).

In arid areas, background soil has a considerable effect on the recorded reflectance by the sensor. Therefore, the indices, which consider background soil reflectance, may signify vegetation characteristics more accurately than the indices such as NDVI (Kallel 2007; Darvishzadeh 2008). In Iran, many studies have been conducted for monitoring drought disaster, in which, mostly AVHRR images and NDVI have been used (Serajian 2000; Baaqide 2007). As AVHRR images have a 1 km resolution it can give a poor estimation for arid areas.

The main objective of this study was to assess the drought severity in central arid areas of Iran by using MPDI as a real time index and ETM+ images which have a higher spatial resolution comparable to the AVHRR images. We examined the substitution of NDVI with another vegetation index (SAVI2, MSAVI, SAVI, PVI and RVI) for accurate estimation of the vegetation fraction which is used for MPDI calculation. Since in this study, the aim is to calculate the drought severity based on single image, three drought indices which needs only one image were selected (Vegetation Supply Water Index(VSWI), MPDI and PDI).

2. MATERIALS

2.1 Study Area

Shirkooh basin is located in the central part of Iran and expands from longitude of 54° 3' to 54° 18' in East and latitude of 31° 27' to 31° 43' in north. It covers a total area of 525 km^2. The altitude varies between 1600 and 4055 meters. The basin is located in arid areas of Iran. Average annual rainfall in the study area is 325.38 mm. The significant amount of rainfall happens during the winter in which agriculture fields and rangeland vegetation depends. Drought which usually occurs in this area causes many problems for its ecosystem.

2.2 Image and Metrological Data

The satellite data used in this research consist of ETM+ images belonging to 19th August 1999 and 10th July 2002. The meteorological data (monthly rainfall) were collected from 18 rain-gauge stations which have 21 years common statistical basis. Table 1 present the annual rainfall of the study area for the considered years. As can be observed from the table, the rainfall increased considerably in 2002 compared to previous years.

Year	Annual (mm)
1999	405.5
2000	134
2001	242
2002	458.97

Table 1. The annual rainfall of the study area.

3. METHODOLOGY

3.1 Image Pre-processing

Since the selected images had different acquisition date, sun angle correction was applied to remove the differences caused by sun. Atmospheric correction was then performed using FLASH algorithm in order to obtain the correct reflectance. After the radiometric pre-processing, the images were geo-referenced using topographical maps in scale of 1/50000 with RMSEs equal to 0.47 and 0.2, respectively.
Since the main objective of this study was to assess drought using different indices, digital numbers recorded by the sensor were converted to the spectral radiance and reflectance using gain and offset parameters provided in the header file of the images.

3.2 Drought Severity by Meteorological Data

Several drought indices based on meteorological data have been introduced by researchers. This includes Palmer Drought Severity Index (PDSI), Standardized Precipitation Index (SPI), Crop Moisture Index (CMI), Reclamation Drought Index (RDI) and etc. each having advantages and disadvantages. In the present research, Run-Test method was used because of its simplicity and also because it only requires annual rainfall. It can be expressed by the equation (1):

$$X_0 = 0.8\bar{P} \Rightarrow \begin{cases} X - X_0 < 0 \Rightarrow Dry \\ X - X_0 > 0 \Rightarrow Wet \end{cases} \qquad (1)$$

Where X = annual rainfall
$\bar{P}$ = average of annual rainfalls

The following parameters can be calculating using this method:
1. Drought duration: the number of consecutive years which drought occurs.
2. Drought magnitude: the total of X- X_0 amounts in each period.
3. Drought intensity: the average of X- X_0 amounts in each period.
4. Drought severity: the maximum amount of X- X_0 in each period.

3.3 PDI and MPDI Indices

Ghulam et al, in 2006, offered a new index based on spectral characteristics of surface in red and near infrared spectral space. As it can be seen from Figure 1, the AD line represents the changes in surface vegetation from full cover (A) to partial cover (E) to bare soil (D), while BC refers to an area with a soil moisture status described as wet (B), drier (D) and extremely dry (C) (Ghulam, 2006).

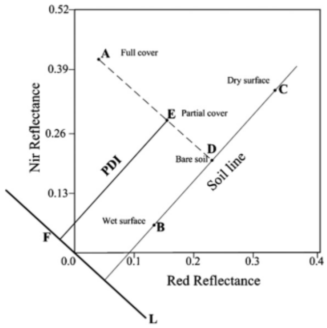

Figure 1. NIR-Red space and PDI (Ghulam, 2006)

The soil line is a linear relationship between NIR and Red reflectance of bare soil (Richardson, 1977). In this paper, in order to obtain the soil line parameters (slope and intercept), about 500 pixels of different types of the bare soils were extracted and were plotted in the feature space of Red-NIR. Here are the soil line parameters for each image:

$$R_{NIR} = 1.19\, R_{Red} + 0.001 \quad \text{(1999 image)}$$

$$R_{\mathrm{NIR}} = 1.19\, R_{Red} + 0.003 \quad \text{(2002 image)}$$

PDI can be calculating using the following equation:

$$PDI = \frac{1}{\sqrt{\alpha^2+1}}\left(R_{Red} + \alpha\, R_{NIR}\right) \qquad (2)$$

where α = slope of soil line

R_Red and R_NIR refer to the atmospherically corrected reflectance of the Red and NIR bands, respectively (Ghulam, 2006).

Crop growth is directly related to the soil moisture. Where soil moisture is below a certain level, crops cannot absorb enough water from the soil and are exposed to drought. Consequently, the soil moisture is the main factor in remote monitoring of drought. Soil spectral reflectance decreases with increasing soil moisture, Therefore, the severity of a drought can be estimated by the close relationship between soil moisture and soil spectral reflectance. However, the spectrum received by the sensor is a mixture reflected or emitted information from different surface targets. Therefore, both the soil moisture status and the vegetation status are very important in drought monitoring.

Ghulam et al, in 2007, suggested a robust drought index which takes into account both, the vegetation status and the soil moisture condition. Therefore, they represented a new index called MPDI which can be expressed as follows:

$$MPDI = \frac{R_{Red} + \propto R_{NIR} - F_V\left(R_{V,Red} + \propto R_{V,NIR}\right)}{(1-F_V)\sqrt{\propto^2+1}}$$
$$= \frac{PDI - F_V PDI_V}{(1-F_V)} \qquad (3)$$

Where, $R_{V,Red}$ and $R_{V,NIR}$ are vegetation reflectances in the red and near infrared bands which in this study was considered 0.05 and 0.5 respectively (Ghulam, 2007). F_v is the percentage of vegetation cover which can be estimated using different methods such as neural networks (Carpenter 1999), linear spectral unmixing (Elmore 2000; Conghe 2005) and vegetation indices (Baret 1995). In the present research, a semi-empirical method presented by Baret in 1995, has been used which expressed as (Baret 1995):

$$F_V = 1 - \left(\frac{VI - VI_{Max}}{VI_{Min} - VI_{Max}}\right)^K \qquad (4)$$

Where, VI_{max} and VI_{min} are vegetation index for a surface with 100% vegetation (F_v=1) and bare soils (F_v=0), respectively. The factor ^{K} is a constant value minimizing the estimation of RMSE which was considered 0.6175 in this study (Ghulam, 2007). The amount of vegetation index was calculated in this study based on the most commonly used indices; they are presented in Table 2.

Vegetation Index	Reference
$RVI = \frac{R_{NIR}}{R_R}$	Pearson & Miller. (1972)
$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}}$	Rouse et al. (1974)
$PVI = \frac{R_{NIR} - \alpha R_{RED} - \alpha}{\sqrt{1+\alpha^2}}$	Richardson & Wiegand, (1977)
$SAVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED} + L}(1+L)$	Huete et al. (1988)
$TSAVI = \frac{\alpha(R_{NIR} - \alpha R_{RED} - \beta)}{R_{RED} + \alpha(R_{NIR} - \beta)}$	Baret et al. (1989)
$MSAVI = \frac{2R_{NIR} + 1 - \sqrt{(2R_{NIR}+1)^2 - 8(R_{NIR} - R_{RED})}}{2}$	Qi et al. (1994)
$SAVI2 = \frac{R_{NIR}}{R_{RED} + (\alpha/\beta)}$	Major et al. (1990)
R_{RED}, R_{NIR} denotes reflectance in NIR and RED wavelengths α and β are the soil line coefficients	

Table 2. Vegetation indices Used in the study

4. RESULTS AND CONCLUSIONS

The results of run-test method indicated that a severe drought with the magnitude of -134.36, the intensity of -67.17, the severity of -121.98 and for the period of 2 years had occurred in 2000 and 2001(Table. 3). On the other hand, meteorological data showed that in April and May when the crops in the study area are at the peak of the growing season and need enough water, monthly rain fall had decreased considerably. Water shortage causes a decrease in the vegetation cover as well as in the seeding of crops. Consequently, the seed bank of the rangeland would be decreased which will result in diminishing of the F_V in the following year (Jangjoo, 2001). Although in 2002, compared to previous years, the rainfall increased considerably (Table 1) it did not affect the percentage of vegetation cover due to the seed shortage in the rangeland.

Year	Annual rainfall	**X-X_0**	Drought status
1999	**405.5**	145.1956	Wet
2000	**134**	-126.304	Dry
2001	**242**	-18.3044	Dry
2002	**458.97**	198.6656	Wet

Table 3. Drought status in the studying years

Changes in the vegetation cover (F_v) of the study area during the time period of 1999 to 2002 has been evaluated using the commonly used vegetation indices (Table. 2) and the equation 4. Among the indices used, only SAVI2 showed the F_V had decreased except in high-land areas where vegetation had no visible changes (Figure 2). In the high-land areas, there is a certain supply of snow until the end of the vegetation growing season and it provides enough water for the vegetation. Consequently, F_V did not change in these areas.

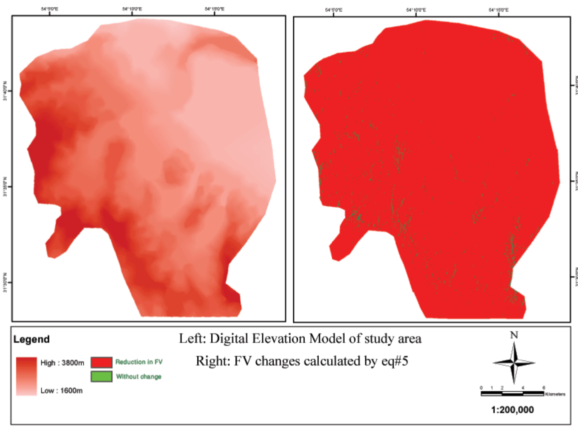

Figure 2. Fraction of vegetation changes (Using SAVI2 and Equation 4)

The study area, since is located in the arid areas of Iran, has sparse vegetation cover and the soil background has a noticeable effect on the recorded reflectance by the sensor. Therefore, RVI and NDVI which are only based on the Red and NIR reflectance are not appropriate indices for assessing vegetation in the arid areas. The results of using these two indices in the current study confirmed this fact and presented vegetation changes as mixed pixels (Figure 3).

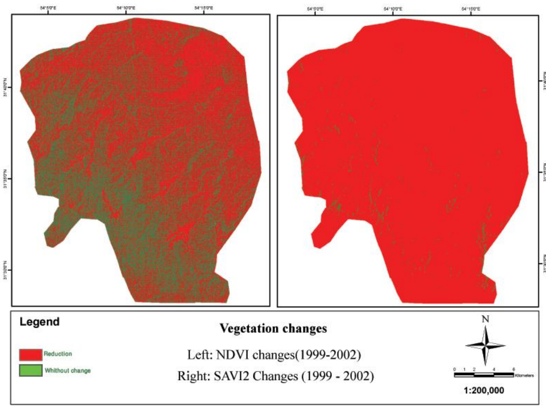

Figure 3. Vegetation changes detected by SAVI2 and NDVI

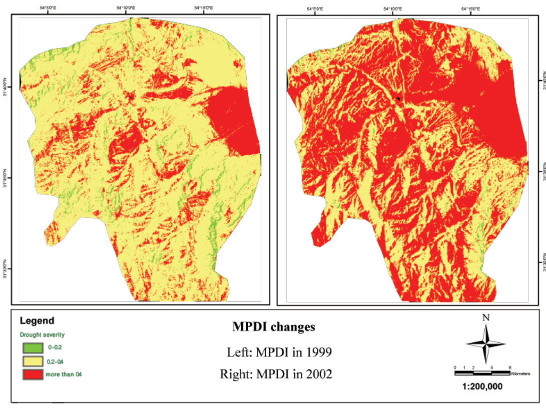

Figure 4. MPDI changes (1999-2002)

Among all other indices, only SAVI2 showed a reduction in the fraction of vegetation. The rest of the indices were also returned mixed pixels.

Next, the drought assessment was examined using three indices: VSWI, PDI and MPDI. As table 1 reveals in 2002, annual rainfall increased sharply. The results of PDI approved that the drought severity decreased. Since the PDI is based on soil moisture and the reflectance of the targets in the Red and NIR bands, it is suitable for meteorological drought monitoring.

On the other hand, the results of VSWI, also, showed mixed pixels. This is due to the fact that this index is based on the NDVI (Carlson 1994) and as mentioned before, NDVI is not appropriate for arid areas.

Ghulam et al, in 2007 used the NDVI to assess drought using MPDI, but as the result showed, this index is not very appropriate for arid areas. Consequently, we examined its substitution with another index. Among all studied indices only SAVI2 had well presented the vegetation fraction (F_v). Therefore, the fraction of vegetation has been estimated using the following index.

$$F_V = 1 - \left(\frac{SAVI2 - SAVI2_{Max}}{SAVI2_{Min} - SAVI2_{Max}}\right)^{0.6175} \qquad (5)$$

The results of the revised MPDI indicated that the area with higher drought severity (more than 0.4) has largely increased (Figure 4). The regions with moderate drought severity were located in the northern and eastern hillside. These regions, keeps the moisture for a longer time. Therefore, the intensity of drought is lower than the other hillsides especially in comparison with the southern hillsides. The lowest values for the revised MPDI appeared in the high-land regions. In the high-land regions, there is snow until the end of the growing season and provide a supply of water for the vegetation growth.

Studying the meteorological data reveals that drought did not occurred in 2002 and the results of PDI confirmed that as well. However, the results of the revised MPDI showed that the drought severity has increased. Therefore, it can be concluded that both meteorological data and the indices based on the satellite images, are essential for an accurate assessment of drought disaster.

In summary, this study had the following conclusions:

1. NDVI is not an appropriate index for vegetation assessment in the arid areas.
2. Vegetation indices which consider soil background reflectance such as SAVI2 can be more useful for vegetation assessment.
3. The PDI is suitable for meteorological drought monitoring.
4. Meteorological data and Remote sensing data are both essential for an accurate assessment of drought.

References:

Baaqide, M. (2007). "Drought monitoring using multi temporal NOAA, NDVI and GIS in Isfahan province." P.H.D thesis, Tarbiat moallem university, Tehran.

Baret, F., Clevers, J., Steven, M.D. (1995). "The robustness of canopy gap fraction estimations from red and near-infrared reflectances." *Remote Sensing of Environment* 54(3): 14–151.

Baret, F., Guyot, G. and Major, D.J., 1989. TSAVI: A vegetation index which minimizes soil brightness effects on LAI and APAR estimation, *Geoscience and Remote Sensing Symposium*, IGARSS'89. 12th Canadian Symposium on Remote Sensing. pp. 1355-1358.

Carlson, T. N., Gillies, R ., Perry, E.M. (1994). "A method to make use of thermal infrared temperature and NDVI measurement to infer surface soil water content and fractional vegetation cover." *Remote Sensing Environment* 9: 161-173.

Carpenter, G., Gopal, S ., Macomber, S .,Martens, S ., Woodcock, C ., Franklin J. (1999). "A Neural Network Method for Efficient Vegetation Mapping." *Remote Sensing of Environment* 70: 326–338.

Chen, W., Xiao, Q ., Sheng, Y. (1994). "Application of the anomaly vegetation index to monitoring heavy drought in 1992." *Remote Sensing of Environment* 9(2): 106-112.

Conghe, S. (2005). "Spectral mixture analysis for subpixel vegetation fractions in the urban environment: How to incorporate endmember variability?" *Remote Sensing of Environment* 95: 248–263.

Darvishzadeh, R., Skidmore, Andrew .,Atzberger, Clement .,Wieren, Sip van. (2008). "Estimation of vegetation LAI from hyperspectral reflectance data:Effects of soil type and plant architecture." *International Journal of Applied Earth Observation and Geoinformation* 10: 358–373.

Elmore, A. J., Mustard, J. F., Manning, S. J., Lobell, D. B (2000). "Quantifying vegetation change in semiarid environments: Precision and accuracy of spectral mixture analysis and the normalized difference vegetation index." *Remote Sensing of Environment* 73: 87- 102.

Ghulam, A., Qin, Q. and Zhan, Z. (2006) Designing of the perpendicular drought index. Environmental Geology.

Ghulam, A., Qiming, Q ., Tashpolat T ., Zhao-Liang L. (2007). "Modified perpendicular drought index (MPDI): a real-time drought monitoring method." *ISPRS Journal of Photogrammetry & Remote Sensing* 62: 150–164.

Goddard, S., Harms, S .,Reichenbach, S ., Tadesse, T .,Waltman ,W.J. (2003). "Geospatial decision support for drought risk management." Communication of the ACM 46 1: 35–37.

Kallel, A., Sylvie, Le., Catherine, O ., Laurence, H. (2007). "Determination of vegetation cover fraction by inversion of a four-parameter model based on isoline parametrization." *Remote Sensing of Environment* 111: 553-566.

Kogan, F. N. (1995a). "Droughts of the late 1980s in the United States as derived from NOAA polar-orbiting satellite data." *Bulletin of the American Meteorological Society* 76(5): 655–668.

Liang, S. (2003). "A direct algorithm for estimating land surface broadband albedos from MODIS imagery." IEEE Trans Geosci *Remote Sensing of Environment* 41(1): 136-145.

Major, D.J., Baret, F. and Guyot, G., 1990. A ratio vegetation index adjusted for soil brightness. *International Journal of Remote Sensing*, 11(5): 727-740.

Pearson, R.L. and Miller, L.D., 1972. Remote mapping of standing crop biomass for estimation of the productivity of the short-grass Prairie, Pawnee National Grassland, Colorado. 8th *International Symposium on Remote Sensing of Environment*, ERIMA, Ann Arbor, MI, pp. 1357-1381.

Pokrovsky, O., Roujean, J-L. (2002). "Land surface albedo retrieval via kernel-based BRDF modeling : 1. Statistical inversion method and model comparison Auditori de Torrent, Spain." Remote Sensing of Environment 84: 100-119.

Richardson, A. J., Wiegand, C.L. (1977). "Distinguishing vegetation from soil background information." *Photogrammetric Engineering and Remote Sensing* 43: 1541–1552.

Rouse, J.W., Haas, R.H., Schell, J.A., Deering, D.W. and Harlan, J.C., 1974. Monitoring the Vernal Advancement of Retrogradation of Natural Vegetation. NASA/GSFC, Type III, Final Report, Greenbelt, MD.

Sandholt, I., Rasmussen, K ., Andersen, J. (2002). "A simple interpretation of the surface temperature/vegetation index space for assessment of surface moisture status." *Remote Sensing of Environment* 79: 213-224.

Serajian, M., Tavakoli, A . (2000). "Investigating drought condition using NOAA images in Iran." Usage of GIS and remote sensing in arid area, Tehran university, Tehran.

Wang, P., Li, X., Gong, J., Song, C. (2001). "Vegetaion temperature condition index and its application for drought monitoring." *International Geoscience and Remote Sensing Symposium*,Sydney, Australia,9–14 July: 141–143.

Zhao, W., Tamura, M ., Takahashi, H. (2000). "Atmospheric and spectral corrections for estimating surface albedo from satellite data using 6S code." *Remote Sensing of Environment* 76: 202-212.