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Application of remote sensing indices in the assessment of meteorological drought for sustainable development

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Abstract : **In recent years, the topic of climate change in effect of greenhouse gases increase has been lionized in scientific studies. The study of meteorological parameters is highly important in hydrology problems, since the same parameters generally form the climate of a region and is due to variations caused by water, wind, rain, etc. Drought as an environmental disaster is associated with a deficit of water resources. Drought is one of the most common natural events that have a great negative impact on agriculture and water resources. Drought is a common natural disaster in many countries as well as Iran. In recent decades with the development of remote sensing, spatial monitoring, temporal drought distribution at different time scales has been become possible. Satellite indices can be used for assessment of different hydrological and climate phenomena. In this research, an index called the RDI and three meteorological satellite indices (NDVI, VCI, SAVI) were used in five regions (Abadeh, Eghlid, Bavanat, Marvdash and Shiraz). The Results showed that the rain effect on vegetation is less for Marvdasht area (9 and 12 months), while it is high for Shiraz (3 months). So it is suggested that in range lands, 6-month time scale of RDI, in forest areas, long term time scales (9 and 12 months) and in rainfed lands, short term time scales (less than 3 month) can be used for drought monitoring.**

1. INTRODUCTION

There are many literatures on the drought evaluation by using different indices, models and water balance simulations Alley, 1985; Jain et al., 2010). There are different indices for drought monitoring, such as: Palmer Drought Severity Index (PDSI), Crop Moisture Index (CMI), Surface Water Supply Index (SWSI), Percent of Normal Index (PN), Standardized Precipitation Index (SPI) (Hayes, 2003; Mishra and Singh, 2010). Along the various indices for meteorological drought monitoring, SPI were widely accepted and used (Hayes and Svoboda, 1999; Tsakiris and Vangelis, 2004; Shamsnia and Pirmoradian, 2009).The SPI was presented by McKee and his colleagues at Colorado State University (McKee et al., 1993). This Index use precipitation as the most effective parameter in the calculation of the drought severity. The SPI is normally distributed so it can be applied to monitor wet as well as dry periods. During the last decade the SPI has become very popular due to its low data requirements. This index can be useful for drought monitoring and forecasting (Cancelliere et al., 2007; Shamsnia et al., 2009). Recently, a new index for drought assessment and monitoring is presented called Reconnaissance Drought Index (Tsakiris and Vangelis, 2005; Tsakiris et al., 2007). RDI is calculated based on precipitation and potential evapotranspiration. Precipitation alone cannot show the impact of drought on agricultural production and vegetation. Applying both of the P and PET in drought severity calculation and monitoring, increases the validity of the results (Tsakiris et al., 2007). Also, this index has a strong correlation with SPI (Asadi Zarch et al., 2011). The RDI was used in Greece (Tigkas, 2008), Cyprus (Pashiardis and Michaelides, 2008), Malta (Borg, 2009) and Iran (Khalili et al., 2011) for monitoring or analysis of historical droughts. In recent decades with the development of remote sensing, spatial monitoring, temporal drought distribution at different time scales has been become possible. The reflected radiations recorded by satellite sensor show the vegetation conditions, type and density for evaluation of agricultural drought (Domenikiotis et al., 2004). There are various indices of satellite-based vegetation condition. Satellite indices can be used for assessment of different hydrological and climate phenomena. One of the most widely used indices is Normalized Difference Vegetation Index (NDVI). (Capodici et al., 2008). This index as a primary tool can be used for assessing vegetation changes and impact of the meteorological parameters on the vegetation. Because of close relationship between vegetation and available soil moisture, NDVI has been used widely to assess drought conditions by directly comparing it to precipitation or drought indices (Jain et al 2010).

The others important indices for drought monitoring are Soil Adjusted Vegetation Index (SAVI) (Huete, 1988) and vegetation condition index (VCI)(Kogan, 1990). In addition to the spectral indices, thermal indices can also be used to assess the vegetation. Many studies have been conducted on the relationship between NDVI, precipitation and drought. Anyamba and Tucker (2005) studied seasonal and annual vegetation in Sahel using NDVI. The correlation between NDVI and rainfall anomaly time series was found to be positive and significant, indicating the close coupling between rainfall and land surface response patterns over the region. Many Studies have focused on the relationships between meteorological and vegetation indices. A study was carried out by Jain et al (2010) on drought monitoring for three areas in India using SPI, normalized difference vegetation index (NDVI), water supply vegetation index (WSVI) and vegetation condition index (VCI) derived from the Advanced Very High Resolution Radiometer (AVHRR). The SPI was computed at different time scales of 1, 2, 3, 6, 9 and 12 months using monthly rainfall data. The NDVI and WSVI were correlated to the SPI and it was observed that for the three stations, the correlation coefficient was high in different time scales. In another study, two satellite-derived indices are used for drought assessment in Thessaly, namely RDI for hydrometeorological drought and Vegetation Health Index (VHI) for agricultural drought. The results showed the drought conditions in Thessaly, using RDI and VHI mapping. The two indices adequately delineate drought features and can be used complementarily, since they describe different types of drought (Kanellou et al., 2008). The main aim of this study is to determine the relationship between two meteorological indices, namely RDI and SPI and identify the differences. So, relationship between NDVI, VCI and SAVI and multi scale RDI are evaluated for drought monitoring.

THE STUDY AREA

Drought is a common natural disaster in many countries as well as Iran. Previous studies show that Iran is exposing drought with different severities (Badripour, 2007; Raziei et al., 2009; Asadi Zarch et al., 2011). To evaluate drought, five regions in Fars Province in the south of Iran were selected. Fars Province with semi-arid and arid climates is one of the most important agricultural parts of the country. This province is located in the southern part of Iran, at 50° 30' to 55° 38' E longitude and 27° 3' to 31° 42' N latitude, with an arable land area of 1.32 million Km^2. The annual mean of precipitation for the province ranges from 50 to 1000mm (Sadeghi et al., 2002). The geographic characteristics and climate of each region for the 9 years (2000 - 2009) are presented in Table. 1. UNESCO (1979) used a system based on average annual precipitation (P) and potential evapotranspiration (PET) for aridity/humidity classification. According to UNESCO, the potential evapotranspiration was calculated using Penman formula. Table 1 indicates the climatic condition of each area.

Table 1. The geographic characteristics, rainfall, PET and climate for each region

Region	Longitude	Latitude	Elevation (m)	P/PET	Climate
Abadeh	52° 40´ E	31° 11´ N	2030	0.094	Arid
Eghlid	52° 38´ E	30° 54´ N	2300	0.220	Semi-arid
Bavanat	53° 40´ E	30° 28´ N	2231	0.204	Semi-arid
Marvdasht	52° 43´ E	29° 47´ N	1596	0.222	Semi-arid
Shiraz	52° 36´ E	29° 32´ N	1484	0.190	Arid

DATA USED

Meteorological data were collected from the Fars Regional Water Authority in a period of 29 years (1981-82 to 2009-2010) for SPI and RDI calculation. The data of TERRA/MODIS were used for satellite indices estimation. The MODIS has several spatial resolutions involved: 250, 500 and 1000meter. In this study, 90 cloud free images MODIS (1000m) were used for a period of 6 years from 2005 to 2010.

METHOD

Calculation of meteorological index

The Reconnaissance Drought Index (RDI)

The Reconnaissance Drought Index (RDI) is calculated in three stages: Initial value of RDI (a_0), normalized RDI (RDIn) and standardized RDI (RDIst). Initial value may be calculated for each month, seasons (3-month, 4-month, etc.) or hydrological year. The a_0 is calculated by using the following equation (Tsakiris et al., 2007; Asadi Zarch et al., 2011)

$$a_0^{(i)} = \frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}}, i = 1(1)N \text{ and } j = 1(1)12 \quad (1)$$

Where P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of the jth month of the ith hydrological year. Hydrological year is starting from October in Iran. N is the total number of years of the available data. A second step, the Normalized RDI (RDI_n) is computed using the following equation for each year, in which it is evident that the parameter a_0 is the arithmetic mean of a_0 values (Tsakiris et al., 2007; Asadi Zarch et al., 2011).

$$RDI_n^{(i)} = \frac{a_0^{(i)}}{\bar{a}} - 1 \quad (2)$$

The third step, the Standardized RDI (RDI_s), is computed following a similar procedure to the one that is used for the calculation of the SPI: The equation for the Standardized RDI is:

$$RDI_{st(k)}^{(i)} = \frac{y_k^{(i)} - \bar{y}_k}{\hat{\sigma}_{yk}} \quad (3)$$

Where y_k is the ln(a_0 ; $\bar{y}_k$) is its arithmetic mean of y_k , and $\hat{\sigma}_{yk}$ is its standard deviation.

The RDI is based on the ratio of two aggregated quantities which are precipitation and potential evapotranspiration. It can be estimated for all time scales. However 3, 6, 9 and 12 month are suggested since they are more useful for comparing different locations (Tsakiris and Vangelis, 2005).

Calculation of vegetation indices

Normalized Difference Vegetation Index (NDVI)

This index is the most common vegetation index and was presented by Rouze et al. (1974). The Normalized Difference Vegetation Index (NDVI) Calculation is based on the near-infrared and red bands. The NDVI equation is:

$$NDVI = \frac{NIR - \mathrm{Re}\,d}{NIR + \mathrm{Re}\,d} = \frac{Channel2 - Channe}{Channel2 + Channe} \quad (4)$$

Where channel 2 & 1 are the reflectance in near infrared and red spectral bands respectively. NDVI ranges are from -1 to +1. NDVI values for vegetation generally range from 0.1 to 0.6. The higher index values associate with greater green leaf area and biomass (Decision Support Center, 2012).When vegetation has been affected by drought and stress, the channel 2 values may decrease and channel 1 values will increase. Using the NDVI equation, the NDVI for different dates were calculated. Then for each region, NDVI values were extracted from the images. The NDVI values were composited and integrated for a monthly time scale.

Vegetation Condition Index (VCI):

Kogan (1990) developed Vegetation Condition Index (VCI) using the ranges of NDVI. VCI equation is:

$$VCI = \frac{(NDVI - NDVI_{\min})}{(NDVI_{\max} - NDVI_{\min})} \times 100 \quad (5)$$

Where: NDVI, NDVImax and NDVImin are weekly or monthly NDVI, maximum NDVI and minimum NDVI in each period and pixel, in a given area.

The VCI values between 50 to 100 % indicate optimal or above-normal conditions. At the VCI value of 100%, the NDVI value for the month (or week) is equal to $NDVI_{max}$. Different degrees of a drought severity are indicated by VCI values below 50% (Thenkabail et al., 2004).

Soil Adjusted Vegetation Index (SAVI):

This index is presented for the first time in 1988 (Huete, 1988). This index is very similar to NDVI and the only difference is in the correction factor The SAVI equation is:

$$SAVI = \left[\frac{NIR - \mathrm{Re}\,d}{NIR + \mathrm{Re}\,d + L}\right] \times (1 + L) \quad (6)$$

L is a correction factor related to the soil. The index values are between -1 to +1.

CORRELATION ANALYSIS

For investigation of relationship between NDVI, VCI and SAVI with different time scales of RDI, correlation analysis and integrated sensing of drought were computed in five regions for period of 6 years from 2005 to 2010.

RESULTS AND DISCUSSIONS:

The relationship between moisture availability conditions were obtained by analyzing the NDVI, VCI, SAVI, and multi scale RDIs with the scatter plots. Results in five areas are presented in the Tables 2 to 6. The relationship between soil moisture and vegetation are investigated using the RDI index. Generally the precipitation amount is different through the growth period and the NDVI index is highly sensitive to precipitation and quickly responds to it during the drought years. The correlation analysis between indices showed that correlation coefficient is different on the various time scales, and correlation amount is even weak on some scales. In another study, it was found that the correlation coefficient was even minus (Ji and Peter, 2003). In this study, there is positive and strong correlation between RDI and NDVI indices at different time scales in Abadeh and Marvdasht (Tables. 6 and 9). The NDVI index shows high and significant correlation between the time scales of 6, 9 and 12 months of RDI in Abadeh (Table. 6) and Marvdasht (Table. 5), with RDI-6 in Bavanat (Table. 4). In these areas, the VCI index has also high and significant correlation with RDI. VCI is the Normalized form of NDVI and known as a strong index in identifying drought effects and vegetation stress. According to this index, drought and vegetation stress occurs when the VCI is less than 35. When VCI is more than 35, it represents normal conditions (Jain et al., 2010). In this study, values of VCI at all areas were less than 35 in the 2008 and affected by drought condition. Bavanat is a range lands (its density is more than 50% in the most parts) and it has the relatively high precipitation and PET. For Bavanat, There is good correlation between NDVI/VCI with SPI-6 which shows the correlation coefficient as 0.421 with NDVI and 0.467 with VCI due to the density of vegetation and the reduction in the soil mask effects (Table. 4). In Marvdasht, studied area (northern part) is the forest area and there is good correlation between NDVI/VCI with RDI due to a type of land use and dense forests. Only in Marvdasht area, the SAVI index shows high and significant correlation at 3, 6, 9 and 12 month time scales that its highest value (r=0.502) is related to the 6-month time scale (Table. 5). The SAVI index calculation is easier than NDVI. The only difference between them is an adjusted coefficient. The value of this coefficient is between -1 to 1. In this study, the same coefficient (l=0.5) in all of the areas were used. The reason for lack of correlation in the other areas can be the difference between the values of the coefficient in the various areas. There isn't strong and significant correlation between the spectral indices with different time scale of RDI in Eghlid (Table. 3). In this area, there are several land uses (Range lands, Forest and Rainfed farming) and the range crops density are low. The reason for the lack of correlation can be the existence of different land uses and the soil mask. There is low-density range, forest and rainfed farming in Shiraz (Qalat area in northern part). There is also moderate correlation between NDVI with RDI-3 due to the different land uses (Table. 6). Based on the growth period, the most of vegetative cover and completion stage of vegetation is from late June to early July in Eghlid and Bavanat. Meteorology data shows, the temperature greatly increases in comparison to previous months in this period. Generally the results indicate the effect of drought and lack of precipitation in Abadeh, Eghlid, Bavant and Marvdasht occurred with a time delay of at least 6 months. In a study which considered the correlation of SPI index on the different time scales with NDVI and WSVI, the results showed that the impact of precipitation on vegetation does not occur instantaneously, but is cumulative. In most cases, 1 month precipitation does not strongly affect vegetation in that month, but the response in notable over periods longer than 1 month (Jain et al, 2010). As regards the objective is the combinational evaluation of meteorological and satellite indices and generating of a double index for more accurate assessment of drought. So the study of correlation is carried out between spectral and thermal indices with RDI meteorology index on different time scales.

Table 2. Correlation coefficient between NDVI, VCI, SAVI and multiscale RDIs and P-Value at 95% confidence level (Abadeh region)

Satellite Indices	Correlation coefficient and confidence level	RDI (1)	RDI (3)	RDI (6)	RDI (9)	RDI (12)
NDVI	r	0.297	0.347	0.455*	0.422*	0.401*
	P-value	0.11	0.06	0.011	0.02	0.029
VCI	r	0.281	0.469*	0.493*	0.486*	0.427*
	P-value	0.132	0.009	0.006	0.006	0.019
SAVI	r	0.332	0.203	0.205	0.162	0.111
	P-value	0.073	0.281	0.277	0.391	0.556

* Correlation is significant at the 95% confidence level

Table 3. Correlation coefficient between NDVI, VCI, SAVI and multiscale RDIs and P-Value at 95% confidence level (Eghlid region)

Satellite Indices	Correlation coefficient and confidence level	RDI (1)	RDI (3)	RDI (6)	RDI (9)	RDI (12)
NDVI	r	0.153	0.099	0.098	0.016	0.006
	P-value	0.420	0.602	0.905	0.934	0.974
VCI	r	0.146	0.317	0.114	0.193	0.213
	P-value	0.441	0.088	0.550	0.308	0.258
SAVI	r	0.241	0.170	0.021	0.601	0.570
	P-value	0.200	0.370	0.912	0.751	0.766

* Correlation is significant at the 95% confidence level

Table 4. Correlation coefficient between NDVI, VCI, SAVI and multiscale RDIs and P-Value at 95% confidence level (Bavanat region)

Satellite Indices	Correlation coefficient and confidence level	RDI (1)	RDI (3)	RDI (6)	RDI (9)	RDI (12)
NDVI	r	0.304	0.345	0.421*	0.337	0.321
	P-value	0.102	0.062	0.021	0.069	0.084
VCI	r	0.268	0.355	0.467*	0.367*	0.304
	P-value	0.152	0.054	0.009	0.046	0.102
SAVI	r	0.280	0.294	0.357	0.284	0.276
	P-value	0.134	0.114	0.053	0.128	0.140

* Correlation is significant at the 95% confidence level

Table 5. Correlation coefficient between NDVI, VCI, SAVI and multiscale RDIs and P-Value at 95% confidence level (Marvdasht region)

Satellite Indices	Correlation coefficient and confidence level	RDI (1)	RDI (3)	RDI (6)	RDI (9)	RDI (12)
NDVI	r	0.192	0.281	0.459*	0.409*	0.405*
	P-value	0.310	0.132	0.011	0.025	0.026
VCI	r	0.202	0.350	0.352	0.391*	0.381*
	P-value	0.285	0.058	0.057	0.033	0.038
SAVI	r	0.318	0.450*	0.502*	0.479*	0.493*
	P-value	0.087	0.013	0.005	0.007	0.006

*Correlation is significant at the 95% confidence level

Table 6. Correlation coefficient between NDVI, VCI, SAVI and multiscale RDIs and P-Value at 95% confidence level (Shiraz region)

Satellite Indices	Correlation coefficient and confidence level	RDI (1)	RDI (3)	RDI (6)	RDI (9)	RDI (12)
NDVI	r	0.329	0.373 *	0.125	0.127	0.144
	P-value	0.076	0.042	0.511	0.504	0.449
VCI	r	0.133	0.331	0.127	0.116	0.127
	P-value	0.483	0.074	0.503	0.542	0.503
SAVI	r	0.289	0.318	0.084	0.142	0.170
	P-value	0.122	0.087	0.660	0.453	0.369

* Correlation is significant at the 95% confidence level

CONCLUSIONS

Assess the drought characteristics, NDVI, VCI and SAVI indices were extracted in the 2005-2010 period, utilizing MODIS images. The multi scale RDI from 1 to 12 months was correlated with spectral and thermal indices and integrated sensing of drought was carried out. In Abadeh, RDI-6 is highly correlated to NDVI/VCI satellite indices than the others. In Bavanat, the RDI-6 with NDVI and VCI is correlated and may be appropriate for drought integrated sensing. In Marvdasht, spectral indices with scales of 9 and 12 month are the most appropriate combinational indices in this area. In Shiraz, 3-month time scale of RDI with NDVI index is correlated. The effect of rain is less in Marvdasht (9 and 12 months) while it is high in Shiraz (3 months). So it is suggested that in range lands, 6-month time scale of RDI, in forest areas, long term time scales (9 and 12 months) and in rainfed lands, short term time scales (less than 3 month) can be used for drought monitoring.

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