DIFFERENT RESPONSES OF MODIS-DERIVED DROUGHT INDICES IN VARIETY OF AGRO-CLIMATIC CONDITIONS

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Abstract

Although drought is a complex phenomenon where its severity is related to the specific climatic region, it can basically be defined as a period of abnormally dry weather, which further results in a change in vegetation cover condition (Heim, 2002; Tucker et al., 1987). Drought is a recurrent climate process that occurs with uneven temporal and spatial characteristics over a broad area and over an extended period of time. Therefore, detecting drought onsets and ends and assessing its severity using satellite-derived information are becoming popular in disaster, desertification, and climate change impact studies. Over the last decades, observations showed that the frequency and intensity of droughts have increased in several parts of the world (Hulme et al., 1993; McCarthy et al., 2001). There has been a large drying trend in many parts of the world over the last three decades (Dai et al., 2005) and many regions have been suffering a water crisis. If this trend continues as expected by climate change scenarios (e.g. by decreasing of precipitation and/or increasing of potential evapotranspiration) in combination with increasing water demand of the population, the consequences may be severe in only a couple of decades and could pose significant water resource challenges to many key sectors (IPCC, 2007; Shindell et al., 2006). Therefore, satellite remote sensing of surface moisture status and drought conditions is of great interest and can contribute for sustainable development of eco-environments.
Recently, a simple method for the estimation of surface dryness, namely the perpendicular drought index (PDI), has been developed (Ghulam et al., 2007a) and further demonstrated to be effective in large-scale applications using Moderate Resolution Imaging Spectroradiometer (MODIS) data (Qin et al., 2008). Regarding inherent constraints and limitations of PDI, Ghulam et al. (2007b) developed a modified perpendicular drought index (MPDI). The MPDI is based on the combination of two important indicators of drought: soil moisture (SM) and fraction of green vegetation (fv). The method shows potential advantages for regional surface dryness estimation, yet its responses on plant cover dynamics at different phenological conditions. Therefore, drought estimation criteria of this index need to be examined further.

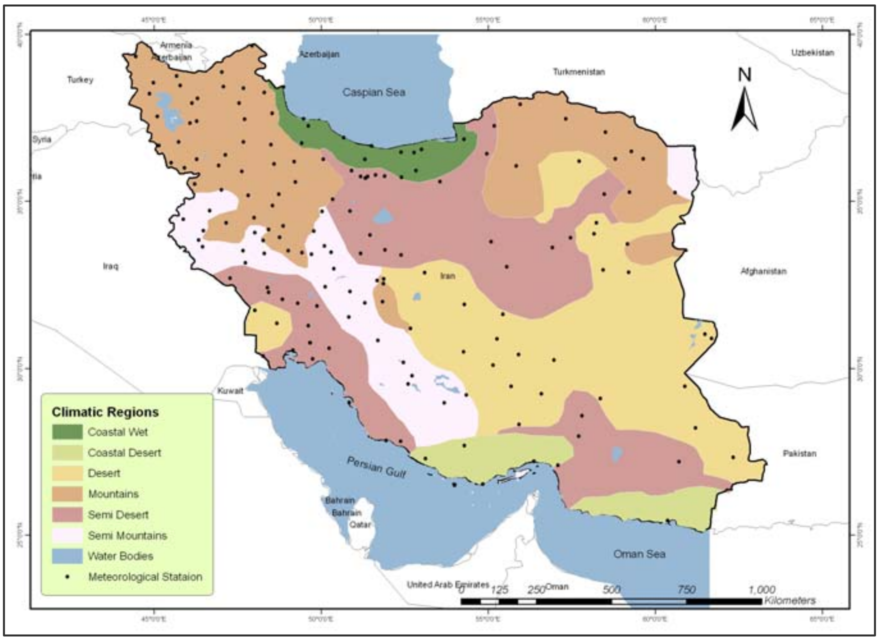

Figure 1. The study area classified into six climatic regions

The main objective of this study is evaluating and refining an appropriate drought estimation method for semi-arid regions, demonstrated for Iran, using remote sensing. Recently developed methods, the Perpendicular Drought Index (PDI), Modified Perpendicular Drought Index (MPDI), Enhanced

vegetation index (EVI) and Vegetation condition index (VCI), are selected as satellite based drought indices in this study. Time series of MODIS satellite images (MOD13A3 V005) have been collected over the region spanning the time interval between February 2000 and December 2005 and PDI, MPDI, EVI, VCI were calculated. Then, these indices were evaluated against meteorological drought indices including Z-score (Z), China-Z index (CZI) and modified China-Z index (MCZI) over 180 meteorological observing stations in Iran (Figure 1).
Results indicate that only in some stations located in mountain and semi mountain regions EVI and VCI have the highest correlation with precipitation. In the other parts of Iran, the MPDI (96 out of 180 stations) and PDI (36 out of 180 stations) show the highest correlation. According to Figure 2, the MPDI index has the highest correlation with precipitation especially in wet regions such as in the coastal wet and mountain regions. The PDI however shows the best results in some parts of the dry regions such as the desert and semi desert regions (Tables 1 and 2). As a main result, it can be concluded that the two remote sensing indices PDI and MPDI show the strongest correlation with precipitation on monthly basis as well as in spatial distribution. In contrast, EVI and VCI do not show statistically enough significant correlation with precipitation in this aspect.

Table 1. The Spearman's correlation coefficients (*r*) for the PDI, MPDI, VCI and EVI versus precipitation.

Climatic Region	PDI	MPDI	VCI	EVI
Coastal Desert	-.269**	-.228**	.211**	.138**
Coastal Wet	-.323**	-.215**	-.042	-.145**
Desert	-.390**	-.379**	.087**	-.061**
Mountains	-.427**	-.334**	-.044**	-.167**
Semi Desert	-.509**	-.482**	.206**	.012
Semi Mountains	-.501**	-.431**	-.005	-.163**

** Correlation is significant at the 0.01 level (2-tailed).

Table 2. The Spearman's correlation coefficients (*r*) for the PDI, MPDI, VCI and EVI versus precipitation in several months.

Month	PDI	MPDI	VCI	EVI
January	-.047	-.110**	.233**	.193**
February	-.199**	-.162**	.189**	.136**
March	-.321**	-.241**	.183**	.100**
April	-.409**	-.336**	.309**	.222**
May	-.585**	-.468**	.497**	.401**
June	-.507**	-.392**	.426**	.346**
July	-.398**	-.331**	.345**	.275**
August	-.386**	-.278**	.266**	.189**
September	-.504**	-.401**	.298**	.193**
October	-.569**	-.435**	.325**	.178**
November	-.488**	-.358**	.376**	.220**
December	-.183**	-.119**	.195**	.149**

** Correlation is significant at the 0.01 level (2-tailed).

For assessing the temporal distribution of indices and comparison of their fluctuations in several climatic regions, the fluctuations of PDI and MPDI versus precipitation at six weather stations representing the six climatic regions of Iran investigated for the period of February 2000 to December 2005(Figure 2).
Both, PDI and MPDI have in general the same reverse behavior to fluctuations of precipitation in several climatic conditions. Whenever a rainfall occurred, PDI and MPDI showed a decreasing trend and inversely in dry periods (no rainfall period) a significant increasing trend. However, these two indices were still varying in the different climatic zones, which mean that the values of PDI and MPDI are related to the climatic conditions as well. As shown in Figure 3a, 3b and 3d in mountainous areas, represented by stations of Mashhad, Shiraz and Abadan, the fluctuations of PDI and MPDI are very similar to each other. Nevertheless, in the rest of regions there are some differences between fluctuations of PDI and MPDI versus precipitation especially at the station Gorgan (Figure 3f). Additionally, it seems that MPDI represented fluctuations of precipitation better than PDI. This is caused by its structure and the consideration of the factors f_v (the fraction of vegetation defined as the

fraction of ground surface covered by vegetation) and R_v,*Red* and R_v,*NIR* (that are pure vegetation reflectance in the Red and NIR bands, respectively), which are very sensitive to dry and wet conditions in vegetated area. This sensitivity has been shown clearly in vegetated climatic regions including the coastal wet, mountain and semi mountain climatic zones which are the most vegetated areas of Iran.

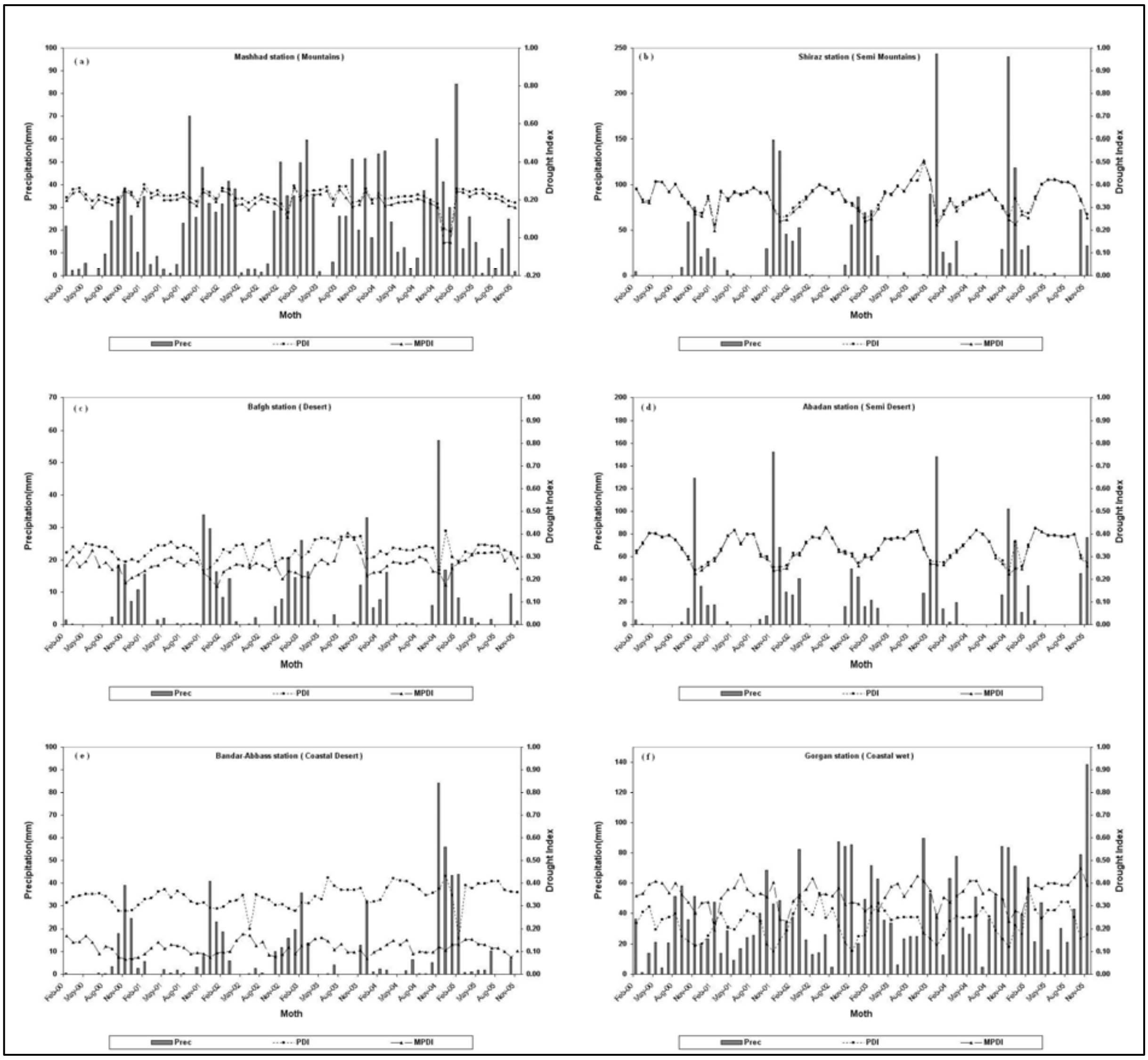

Figure 2. Temporal distribution of remote sensing indices (PDI and MPDI) vs. precipitation during Feb. 2000 to Dec. 2005 of six climatic regions in Iran;
(a) Mashhad station located in mountain climatic region, (b) Shiraz station located in semi mountain climatic region, (c) Bafgh station located in desert climatic region, (d) Abadan station located in semi desert climatic region, (e) Bandar-abbass station located in coastal desert climatic region, (f) Gorgan station located in coastal wet climatic region.
(The X–axis represents the time (month), the left Y-axis represents PDI and MPDI and the right Y-axis represents precipitation (mm). Each panel belongs to a weather station located in one of six climatic regions).

In developing countries gaps in meteorological data in both temporal and spatial scales are frequently observed. Additionally the necessary quality of meteorological data is not always given and significant delay from measurement time and data providing can occur. For that reasons it is suggested to use remote sensing drought indices as a powerful agricultural drought monitoring tool for both vegetated and bare surface as shown in this paper. However, before application, analyzing of thresholds by using field observations is strongly recommended.

Keywords: drought monitoring, drought indices, drought classes, remote sensing.

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