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Seasonal comparisons of meteorological and agricultural drought indices in Morocco using open short time-series data

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Although the preliminary investigations of NDWI demonstrated its sensitivity to vegetation water content, drought indices based on NDWI short time-series are still understudied compared to those derived from NDVI and LST, such as VCI, SVI and TCI. On the basis of the open data, this paper introduces a new index derived from NDWI short time-series, and explores its performance for drought monitoring in Mediterranean semi-arid area. The new index, Standardized Water Index (SWI), was calculated and spatiotemporally compared to both meteorological drought index (TRMM-based SPI) and to agricultural drought index (NDVI-based SVI) for the hydrological years and autumn, winter and spring seasons during a period of 15 years (1998–2012). Furthermore, the response and spatial agreement of the meteorological and agricultural drought indices (SWI, SVI and SPI) were compared over two land use classes, rainfed agriculture and vegetation cover, for the studied years and seasons. The validation of SWI was based on in situ SPI and cereal productions. The analysis of the 336 cross-tables, proportions of concordance and Cohen's kappa coefficients indicate that SWI and SVI are concordant comparing to other combinations for hydrological years and for the three seasons. The study points that the spatial agreements of drought indices over rainfed agriculture and over vegetation cover are different. It is relatively more important in the rainfed agriculture than in the vegetation cover areas. Our results show that the agreement between vegetation drought indices and meteorological drought indices is moderated to low and the SPI is slightly more concordant with SWI when it is compared to SVI in autumn and winter seasons. The validation approach indicates that drought affected area, according to SWI, is highly correlated with cereal production. Likewise, a satisfactory correlation was revealed between SWI and in situ SPI.

1. Introduction

Drought is still a major hindrance to sustainable development in Morocco; its serious impacts are agricultural, socio-economical and environmental. It is a recurring phenomenon that affected all Moroccan regions with different intensities, durations and spatial extents. This is clearly proved by the reconstruction of the past droughts events and characteristics through long-term tree-rings series in Morocco for the 1000-years (Chbouki, 1992; Esper et al., 2007), and the historical documents relevant to the last centuries (Naciri, 1985). Likewise, the expectation of the Intergovernmental Panel on Climate Change (IPCC) confirms that drought and flood will be more frequent due to climate change in the Mediterranean area, including Morocco (IPCC, 2007). It is the same for Born et al. (2008), who showed that Moroccan climate tends to change toward warmer and drier conditions. As far as the historical, present and projected drought frequency is concerned, this phenomenon seems to be a structural component of Moroccan environment.

In the literature, many drought indices have been globally used in different contexts for drought characterization and monitoring. Such a variety can be explained according to the many disciplines by which they are perceived and also by the diverse sectors affected by drought. Nevertheless, the scientific community agreed that drought indices are derived into four classes, i.e. meteorological, hydrological, agricultural and socio-economical. Among widely used drought indices one can mention Palmer Drought Severity Index (PDSI) (Palmer, 1965) and Standardized Precipitation Index (SPI) (McKee et al., 1993). This latter was recommended to be used as a universal meteorological drought index according to Copenhagen declaration (WMO, 2009). SPI has several advantages, in fact, it is easy to calculate and it requires only rainfall data, additionally, it has the possibility to be implemented at different time scales and to be compared over different regions, since it is standardized. The main constraint for the operational use of the SPI is its local character. As the other in situ indices, its spatial interpolation over

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a region or watershed requires a good density and distribution of meteorological stations (Rhee et al., 2010; Mozafari et al., 2011).

Earth observation data has overcome this constraint by providing spatial drought indices with a regular frequency. The contribution of satellite-based indices to drought characterization and spatiotemporal monitoring in different regions around the world has been well documented (Singh et al., 2003; Bhuiyan et al., 2006; Son et al., 2012; Zhang and Jia, 2013; Du et al., 2013; Wu et al., 2013), to name few. The commonly used satellite drought indices can be regrouped into four categories reflective indices, thermal indices, rainfall based indices, and their different combinations. The Normalized Difference vegetation Index (NDVI) time-series, extracted from the reflectance radiated in the near-infrared and visible red wavebands, were widely used for the calculation of several drought indices. Vegetation Condition Index, (VCI) (Kogan, 1995a,b) and Standardized Vegetation Index (SVI) (Liu and Negron-Juarez, 2001; Peters et al., 2002) are typical examples of these categories, since they were widely used for drought characterization and monitoring (Bajgiran et al., 2008; Quiring and Ganesh, 2010; Gebrehiwot et al., 2011; Du et al., 2013). The VCI is calculated in function of minimum and maximum NDVI value compiled per pixel over a time-series, whereas SVI is based on the calculation of *Z* scores, a deviation of the NDVI mean in units of standard deviation at the level of each pixel over a time-series. Among the examples of the used thermal drought indices, it can be cited the Temperature Condition Index (TCI) (Kogan, 1995a,b) which is calculated on the basis of maximal and minimal brightness temperature at level of pixel over a time-series. This index was implemented in different regions (Bhuiyan et al., 2006; Bayarjargal et al., 2006; Du et al., 2013).

The combination of the indices derived from near infrared, red and thermal wavebands for drought monitoring attracted the researchers interest. The Vegetation Health Index (VHI) (Kogan, 1997, 2000) is an example of this category. It is based on an additive combination of TCI and VCI. This index proves more satisfaction compared to VCI or TCI alone (Kogan et al., 2004). It was used to assess agricultural drought probability over Africa (Rojas et al., 2011). Recently, VHI has showed greater performance in detecting drought when it was evaluated by streamflow and soil moisture measurements in the Little River Experimental Watershed, Georgia, USA (Choi et al., 2013). Drought Severity Index (SDI) (Bayarjargal et al., 2006), calculated as subtraction of standardized LST and NDVI, indicated a similarity with VHI when it was compared to other reflective and thermal indices in the Mongolia's desert and desert-steppe geo-botanical zones (Bayarjargal et al., 2006). Temperature vegetation dryness index (TVDI), (calculated by parameterizing of the relationship between the NDVI and LST data), was explored in the Lower Mekong Basin. The findings showed a close agreement between TVDI and TRMM as well as a good correlation between TVDI and soil moisture (Son et al., 2012). The combination of reflective indices, thermal and precipitations ones was also examined. Brown et al. (2008) introduced a composite index, VegDRI, which integrates vegetation condition, station-based drought indices and information about land use, land cover and soils. Rhee et al. (2010) proposed a new multi-sensor drought index, called the scaled drought condition index (SDCI) which used NDVI, LST and TRMM data. The SDCI was compared to NDVI and VHI on the basis of in situ drought indices in the arid region of Arizona and New Mexico and also in the humid region of North Carolina and South Carolina. The results revealed that it is more performing (Rhee et al., 2010). Du et al. (2013) proposed a Synthesized Drought Index (SDI) based on the integration of VCI, TCI and TRMM precipitation products condition index (PCI) through principal component. It was demonstrated that SDI is highly correlated to SPI, crop yield and to drought affected area in China Shandong province (Du et al., 2013).

The potentialities of satellite near-infrared, red and thermal channels have been widely explored, through NDVI, LST and their combinations. However, the contribution of shortwave infrared (SWIR) is still in development phase and urges investigation. Normalized Difference Water Index, calculated from SWIR and Near Infrared, is known to be sensitive to vegetation water content (Gao, 1996) and may hold an important potential for drought monitoring. A quantitative analysis of bias and standard error of NDVI and NDWI, extracted from Landsat Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM+), showed that NDWI has a superior relationship with ground-based vegetation water content measurements in Walnut Gulch Watershed (Jackson et al., 2004). Such authors suggest exploring the same approach on the basis of MODIS. NDWI values, extracted from MODIS, exhibited a quicker response to drought conditions than NDVI in Flint Hills of Kansas and Oklahoma (Gu et al., 2007). The same study showed that Normalized Difference Drought Index (NDDI), which is calculated in function of NDWI and NDVI, according to this formula ((NDVI-NDWI)/(NDVI + NDWI)), is more responsive and have wider dynamic range value than simple difference of NDVI and NDWI (Gu et al., 2007). A recent study, carried out in Sahara–Sahel transition zone, demonstrated the performance of NDWI multi-temporal series derived from Landsat-TM and ETM+ to detect permanent and seasonal water (Camposa et al., 2012). NDWI preliminary findings are encouraging, but more investigations are needed in order to explore with more details its potentialities for drought monitoring. Furthermore, NDWI time-series based drought indices is still understudied compared to those derived from NDVI and LST time-series (VCI, TCI and SVI). Throughout the literature review, it is shown that no NDWI times-series drought indices have been established till now. This line of research warrants investigation and its exploration will be initiated in this paper through a new NDWI short times-series based index.

It is confirmed that spatiotemporal comparison and correlation of satellite-based drought indices was subject of some investigations in order to evaluate drought indices compatibilities and to infer the most relevant index for decision-making. NOAA–AVHRR reflective indices (NDVI, NDVIA, SVI and VCI), thermal index (TCI) and their combinations (LST/NDVI, VH, and DSI) were compared over the desert steppe and desert geo-botanical zones of Mongolia (Bayarjargal et al., 2006). The study demonstrated that the spatial agreement of the studied indices are generally low, and the reflective indices shows higher correlation, while a lesser or no relationship is found between the thermal and combination of the thermal and reflective indices (Bayarjargal et al., 2006). A well detailed analysis of spatial and temporal drought dynamics was made during monsoon and non-monsoon seasons in the Aravalli region on the basis of VCI, TCI, VHI (extracted from NOAA-AVHRR) besides SPI and SWI (computed respectively from rain-gauge stations and wells) (Bhuiyan et al., 2006). The study found that no linear correlation exist among meteorological, hydrological, and vegetative droughts indices in the studied region, it also revealed an increase of the correlation between SPI and VCI during the monsoon season (Bhuiyan et al., 2006). VCI has been compared to five different meteorological indices, namely Palmer Drought Severity Index (PDSI), Moisture Anomaly Index (*Z*-index), Standard Precipitation Index (SPI), percent normal, and deciles in Texas counties (Quiring and Ganesh, 2010). It is worth noting that VCI is the most highly correlated one with the 6-month SPI, 9-month SPI and PDSI. Furthermore, the relationship between VCI and meteorological indices is significantly variable in space. Compared to counties in eastern Texas and along the Gulf Coast ($R^2 < 0.1$) (Quiring and Ganesh, 2010), the counties in northwestern and southwestern Texas have much higher correlations ($R^2 > 0.6$). Another comparison of standard and remotely sensed drought indices was conducted by Choi et al. (2013) in the Little River Experimental Watershed, Georgia, USA. It revealed that the Evaporative Stress Index (Computed from the ratio of potential and actual evapotranspiration), VHI, and PDSI had been