academicJournals

Vol. 6(5), pp. 144-154, May, 2014
DOI: 10.5897/IJWREE2013.0414
Article Number: 9BDBD5744834
ISSN 2141-6613
Copyright © 2014
Author(s) retain the copyright of this article
http://www.academicjournals.org/IJWREE

International Journal of Water Resources and Environmental Engineering

Full Length Research Paper

Assessment of Silyaninov index for detecting climatic changes and droughts in the central Sudan

M. A. Shamseddin[1] and H.S.M. Hilmi[2]*

[1]Water Management and Irrigation Institute, University of Gezira, P. O. Box 20, Wadmedani, Sudan.
[2]Faculty of Agriculture, Alzaiem Alazhari University, Khartoum North, P. O. Box 1432, Sudan.

Received 13 May, 2013; Accepted 6 May, 2014

Drought is a constraint upon development in Sudan. This paper attempts to understand drought and climate change in the central Sudan using the Silyaninov index (SI) because of its simplicity and its required datasets (monthly rainfall and temperature) are routinely collected in developing countries. Also, the ecoclimatological relationships for the natural vegetation cover were investigated using the normalized difference vegetation index (NDVI) and ancillary climatic data. The climate variability in the central Sudan is found to be highly generated by the variability in rainfall rather than temperature. Rainfall experienced a significant decreasing trend (≈ 3.5 mm per annum) coupled with a significant increasing trend in temperature (≈ 1.4°C per annum) during the period 1960 to 2010. Accordingly, the aridity increased significantly at 50% of the studied stations. SI is found to be more effective in detecting drought than using rainfall dataset alone. However, when the temperature dataset is anomalies-free it could explain effectively most of the historical meteorological droughts witnessed in central Sudan. Using SI, the majority of the drought events were observed in 1970 to 1990, with the exception of Damazine (1998 to 2002) and Ed Duim stations (2000 – 2005). The common wetted years outweighed the common drought years, revealing the localized behavior of the rainfall. The analysis of NDVI showed that the vegetation cover experiences a decreasing pattern under the semi dry (Ed Duim station) and semi humid (Damazine station) climatic zones during the period 2000 to 2010. The relationships of NDVI-SI and NDVI-rainfall were found better than the NDVI- temperature.

Key words: Central Sudan, drought, climate change, natural vegetation cover, Silyaninov index, normalized difference vegetation index (NDVI).

INTRODUCTION

According to the Intergovernmental Panel on Climate Change, IPCC (2007) climate change is defined as a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Thus, it refers to any change in climate over time, whether due to natural variability or as a result of human activity. These changes will likely lead to changes in rainfall, atmospheric moisture and regional climate variability, especially in the tropics and sub-tropic areas (Gitay, 2002). Most of the climate change studies have been

*Corresponding author. E-mail: hilmi.aau@gmail.com, shams_id@yahoo.com
Author(s) agree that this article remain permanently open access under the terms of the Creative Commons Attribution License 4.0 International License

done in large scales. This is necessitated downscaling studies, as the impacts of climate change will be different from one place to another (IPCC, 2007). For instance, it is expected that Africa will likely be the most vulnerable continent (Challinor et al., 2007).

Drought is an ordinary phenomenon in the eastern African countries, including Sudan. It has affected 100% of the land in Somalia, Eritrea and Djibouti, and 61 to 87% of the land in Ethiopia, Kenya and Sudan (Mati, 2005). The periods 1970s and 1980s were the most decades that have witnessed catastrophic results due to droughts that is, mass lost of souls, destroyed vegetation covers, failure in biomass production, displacement and social stability (Osman and Shamseldin, 2002; Sivakumar et al., 2005; Tilahun, 2006). In Sudan, drought has been related to famine, civil unrest, ill-health and desertification and in turns as a constraint upon development (Hulme, 1987). Ayoub (1999) has reported that the repeated droughts of the late 1960s to mid 1970s have resulted in destroying the whole of *Acacia tortilis* belt of north Kordofan, and in increasing the number of dust storms per year during the period of 1970 to 1980 in El Fasher area, Darfur region.

Climate change and drought pose great threats to human life, economic sectors and environments. Therefore, their quantitative monitoring is very important from many perspectives of views: risk management, assessing adaptive capacity, planning and decision making process. The better drought preparedness depends on monitoring drought's onset, progress and real extent (Morid et al., 2006). However, drought is very difficult to define. For example, Logan et al. (2010) cited more than 150 definitions for drought. This is because drought is not a distinct event, it is as a result of complex factors and it has neither a distinct start nor a finish; it is only after a period of time it can be recognizable (Oladipo, 1985). One of the definitions of drought that had been formulated was that "a sustained period of significantly below normal precipitation". This definition encounters two problems. Firstly, there was no universal agreement on the definition of "a sustained period". Secondly, due to the high variability of rainfall the term norm precipitation is questionable in the African Sahel (Hulme, 2001). In Sudan, Ayoub (1999) has called that there is a southward shifting of the desertification boundaries, which can be considered as a climatic change. It goes without saying that aridity is universally distinguished from the drought as the former is a permanent climate feature of a given region resulting from low precipitation.

Generally, there are four wide types of drought; viz: meteorological, agricultural, hydrological and socioeconomic droughts. The widely natural and human factors used to designate drought are climate, soil water, precipitation, soil type, water storage distribution, number of population and land use (Oladipo, 1985). In order to monitor drought, many indices have been devised, such as the ratio of precipitation and potential evapotranspiration, the standardized precipitation index (SPI), the evaporation ratio, the Palmer drought severity index (PDSI) and the soil moisture index (Arora, 2002; Ntale and Gan, 2003; Sivakumar et al., 2005; Bates et al., 2008; Mpelasoka et al., 2008; Logan et al., 2010). Ntale and Gan (2003) found that SPI is the most appropriate method for detecting the regional east African droughts, agrees with Morid et al. (2006) results for Tehran Province conditions in Iran. However, the preciseness of the SPI depends on the rainfall distribution and its length of record (Wu et al., 2005).

Recently, the drought indices have been used for detecting climate change. Mavromatis (2010) found that the self-calibrated version of PDSI has the potential to be used for climate change impacts assessment studies. In Sudan, climate change impacts are poorly documented. Rainfall remains the most studied climatic variable (Hulme, 1986, 1987; Eldredge et al., 1988; Ayoub, 1999; Fud Elmoula, 2004). Temperature datasets are commonly available but not so studied. Thus, from cost effective and data availability point of view both temperature and rainfall could be effectively used in studying climate change and drought in Sudan.

The Silyaninov index is historically used in classifying the climatic zone of Sudan, seven climatic zones (Table 1). By such mean, detecting any prolonged changes in SI values may indicate a climatic change. There are discernable reasons behind using of SI to detect climate change and drought for the central Sudan: (1) Adam (2002) designated the critical values for every climatic zones in Sudan, these values can be used as baselines, given that the persistent changes in those values can be considered as a climate change; (2) SI is very easy to estimate since its estimation depends on the most two reasonably available climatic variables in Sudan, viz. rainfall and temperature.

Agriculture and livestock breeding are the dominant livelihood generations in central Sudan. Thus, drought and climate change are expected to have detrimental impacts on communities stability. It is therefore, studying the relationship between climate and vegetation cover is very important. Recently, remote sensing techniques were widely used in monitoring vegetation cover, agriculture, natural resources, weather conditions, water balance and droughts (Bastiaanssen et al., 2003; Omuto and Shrestha, 2007; Tan, 2007; Elhag and Walker, 2009; Mavromatis, 2010). Also, remote sensing has been used recently to define aridity as Lioubimtseva et al. (2005) reported that a period with a natural difference vegetation index (NDVI) value of less than 0.07 (a unit less) is classified as arid. The huge advance in the remote sensing techniques makes them capable for studying precisely the climate changes impacts on vegetation cover dynamics in central Sudan. As yet the define of drought years in the central Sudan is depended on memories of local people (Abusin, 1986; Telku et al.,

Table 1. Sudan's climatic zones, on the basis of Silyaninov index (SI).

Climate type	Value of SI
Desert	< 0.1
Sem-desert	0.1-0.3
Dry	0.3-0.5
Semi-dry	0.5-0.7
Sub-humid	0.7-1.3
Humid	1.3-2.0
Super-humid	> 2.0

Source: Adam (2002)

1991), the objectives of this study were to detect climate change and drought using the Silyaninov index (SI) because of its simplicity and required datasets (monthly rainfall and temperature) are generally available in developing countries in the central Sudan. Also, the study examines the dynamic of the natural vegetation cover using the NDVI.

Description of the study area

The study area was located between 11.00 to 14.38 °N and 24.8 to 35.4 °E, which roughly represents the central Sudan with a total area of 434 000 km^2 (Figure 1). The climate is generally hot and dry, ranging from dry to sub humid zones. Rainfall and length of dry season are the most significant climatic variables (Food and Agriculture Organization of the United Nations, FAO, 2006). Rainfall extends for a short period (June to October) with a low magnitude, ranging from 100 in the northern part to 600 mm in the southern part. This is coupled with a high annual evapotranspiration of 2200 mm. Thus, the region suffers shortage in the water supply for a long period of time (8 months).

Central Sudan is distinguished as the main region of both animals and agricultural productions. It includes most of the Sudanese irrigated and rainfed agricultural projects. There is however, a delicate balance between man needs and natural resources as the vast majority of the livelihood generations, basically agriculture and rearing livestock are climate-land-based, especially in rural areas. Both climate and land however, have been deteriorated and in turns disturbed the region's socio-economic stability (Hulme, 1986; Ayoub, 1998). Add to this, the region belongs to the African Sahel belt where drought is a repeatable problem. Moreover, the evidence of the 1984/1985 famine states that drought is the main cause of famine in Sudan (Teklu et al., 1991).

MATERIALS AND METHODS

The first step for detecting climate change and droughts in the central Sudan is to choose the representative stations. To ensure the statistical validity, the station with a minimum record length of 25 years was chosen (Table 2). This restricted the number to only eight stations. Many stations have been found out of service since 1970s and 1980s (Figure 1), especially at the western part, that is, Kordufan and Darfur, due to drought episodes that is leading to instability and insecure situations. Therefore, each station is expected to cover about 54 000 km^2 from the total area, indicating poor spatial meteorological measurements in the central Sudan. Therefore, stationary data series are used instead of the regional ones.

Testing data quality

In order to detect trends in the time series, the following tests were applied in advance.

Test for homogeneity

The nonparametric Thom test was used to examine the homogeneity of the time series, following the procedure mentioned in Rodrigo et al. (1999), Modares and Silva (2007) and Nasri and Modares (2009). The null hypothesis (the time series is homogeneous) is verified at the 0.99 confidence level if $|Z| < 2.58$. The time series of rainfall were found homogeneous. However, temperature time series of 50% of the stations (namely Damazine, El Obied, Wadmedani and Gedarif stations) were found to be inhomogeneous. Consequently, the cumulative residuals method was used to apply the appropriate corrections as described in Allen et al. (1998).

Test for randomness

The presence of a positive correlation will increase the possibility of rejecting the null hypothesis (no trend) while it is actually true and the vice versa is correct for the negative correlation (Yue and Wang, 2004). The detection of trend in a time series entails that the datasets is serially independent (Yue and wang, 2004). Therefore, the Durbin-Watson test was used. It is found that all the stations, with the exception of Gedarif and Damazine, have shown significant positive serial correlations (P = 0.05). To eliminate such serial correlation, the pre-whitening approach was adopted, following the approach described in Burn and Hag Elnour (2002).

Test for trend

The non-parametric Mann-Kendall test was used to detect trends in time series as described in Burn and Hag Elnur (2002), Yue et al. (2002), Smith et al. (2004), Yue and Wang (2004), Modarres and Silva (2007), Luo et al. (2008), Basistha et al. (2009), Nasri and

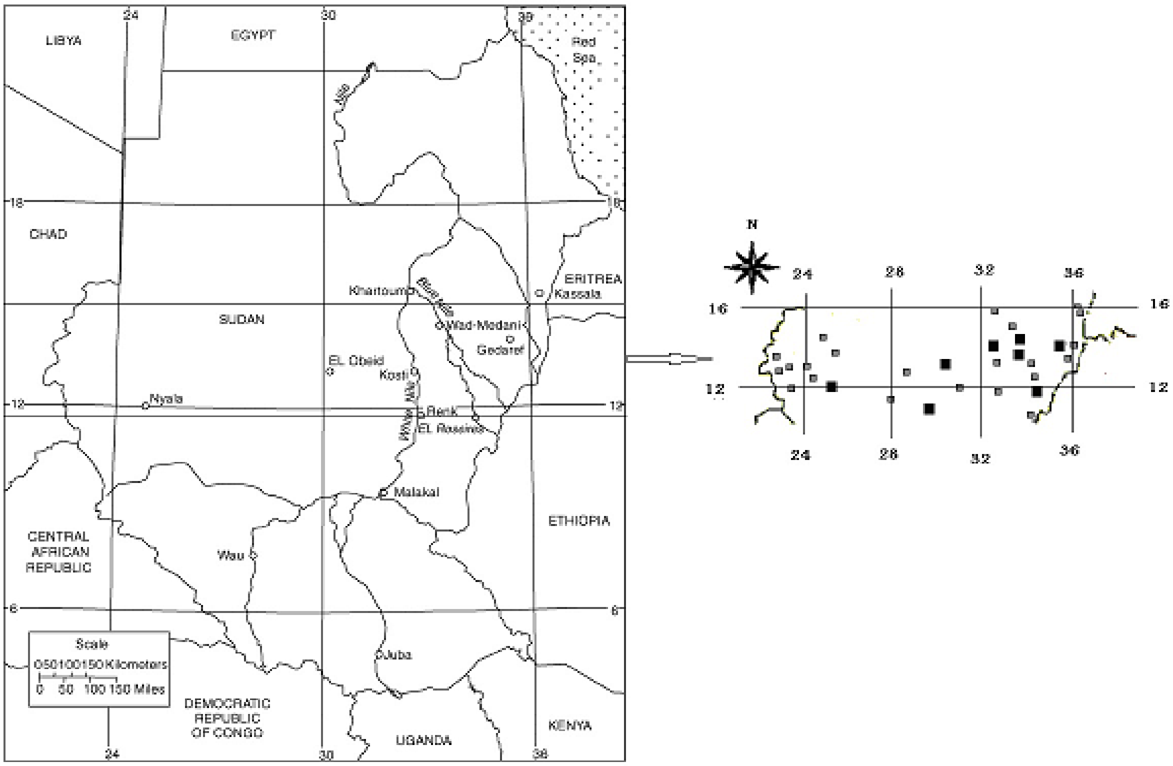

Figure 1. The studied stations (the black squares) in the central Sudan. The grey squares refer to the stations with problems in data availability

Table 2. The locations, altitudes and sample sizes of rainfall (R-N) and temperature (T-N) for the selected stations in the central Sudan.

No.	Station	Latitude (°N)	Longitude (°E)	Altitude (m)	R-N (year)	T-N (year)
1	Kadugli	11.00	29.72	500	47	41
2	Damazine	11.82	34.40	470	43	41
3	Nyala	12.00	24.80	675	36	39
4	El Obied	13.17	30.23	570	43	43
5	Sennar	13.55	33.56	420	36	40
6	Ed Duim	14.00	32.33	378	36	40
7	Gedarif	14.03	35.40	600	43	42
8	Wadmedani	14.38	33.48	405	47	41

Modarres (2009), and Xu et al. (2010). The magnitude of change, expressed as percentages of mean, is determined by the Theil and Sens's method (Burn and Hag Elnour, 2002; Basistha et al., 2009).

Detecting drought and climatic changes using Silyaninov index (SI)

Several methods have been used to classify Sudan's climate, among them Silyaninov index (SI) was found the best (Adam, 2002; Fud Elmoula, 2004; El Fadni, 1998). It's goodness is likely rose from the climatic variables used in its estimation, viz. rainfall and temperature, that is, moisture and thermal factor, which both play a vital role in the climate of the tropics (Fud Elmoula, 2004). For example, Tan (2007) points out that rainfall and temperature control most of the differences in the Earth's vegetation cover, affecting growth rate and plant reproduction. The SI is defined as a ratio between the annual rainfall and the cumulative annual temperature above 10°C as described below (Adam, 1995; Fud Elmoula 2004):

$$SI = \frac{R * 10}{C.T} \quad (1)$$

Where, R is the mean annual rainfall (mm) and $C.T$ is the cumulated annual temperature (°C). The stationary data lengths are shown in Table 2.

The preciseness of the SI in detecting drought is calibrated using the fragmentally documented historical drought events in Sudan, which have been well cited in Leku et al. (1996) and Abusin (1986). The recent drought events (1996 to 2010) were judged using the average crop yields of the period 1974-1982 as a baseline. Data of crop yields were obtained from the records of the ministry of agriculture and FAO reports. Type I errors i.e. the rate of rejecting the null hypothesis of no drought is computed by Clark and Schkade (1969)

$$\sigma p = \sqrt{\frac{\pi(1-\pi)}{n}} \quad (2)$$

$$z = \frac{pc - \pi}{\sigma p} \quad (3)$$

Where, P_c is the critical value of the sample percent, π is the value of the universe percent designated in the null hypothesis and σ_p is the standard error of the percent, *z* is taken as 1.96 which is corresponding to the value of 0.025 in one tail of the normal distribution and *n* is the random sample size. In this case, type I errors (rejecting the null hypothesis while in fact it is true) can be determined by management. The critical values were taken as the means of the upper and lower values designated to each climatic zone in Table 1.

NDVI estimation

This section deals with expected impacts of climate change and drought on the vegetation cover in central Sudan.Two Acacia Senegal forests (Perennial trees) were chosen through a surveying trip using a Global Positioning System (GPS). The first forest is located (11.56 °N and 34.23 °E) in the Damazine region (Blue Nile state, southern-eastern part of the study area) where the climate is sub humid. The second forest (13.24 °N and 35.85 °E) locates in the Gedarif region (Eastern part of the studied area) under semi dry climate conditions. The soil of both forests is heavy clay with a water holding capacity of 230 mm/ m depth. Thus, these forests are anticipated to reflect the long term impacts of climate change on the vegetation cover, soil moisture content and groundwater. The sizes of both forests (roughly 22 000 ha) are large enough to be compatible with the satellite images of coarse resolutions such as of the Moderate Resolution Imaging Spectroradiometer (MODIS). The MODIS-derived NDVI values were downloaded with a spatial resolution of 250 x 250 m and a temporal resolution of 15 days for eleven consecutive years (2000-2010). The ecoclimatological single variable relationships of NDVI, rainfall, temperature and aridity were examined on the basis of Pearson correlation (r). In order to eliminate seasonality impacts the standardized values were used by subtracting the mean and then dividing by the standard deviation.

RESULTS AND DISCUSSION

Trends in time series

The descriptive statistics of annual rainfall and temperature (mean, coefficient of variation (CV), skewness (CS) and kurtosis coefficient (CK)) are presented in Tables 3 and 4. The mean value of annual rainfall and temperature are found to be 219 to 662 mm and 25.5 to 29.3°C, respectively. The coefficient of variation of rainfall (30%) is higher than that of the temperature (2%), suggesting that rainfall controls the climate variability in the central Sudan.

The obtained mean SI value is ranged between 0.33 and 1.01, revealing that there were three distinct climatic zones in the central Sudan. These are dry, semi dry and sub humid. However, these climates are very variable since SI is associated with a high coefficient of variation of 29%. The coefficient of variations of both SI and rainfall are found equal, restating that rainfall is the determinant factor in the region's climate. This finding has been further tested as the relationship between the peaked-nesses of SI (wettest situation) and rainfall is higher (r ≈ 0.89) than that of the temperature (r ≈ 0.47). Trends in rainfall, temperature and SI are shown in Tables 5 and 6. At 55% of the cases, the annual rainfall shows a statistically significant decreasing trend of 3.5 mm per annum. This is coupled with a statistically significant increasing trend of 1.4°C per annum in temperature at 100% of the cases. Accordingly, SI showed a decreasing trend, suggesting that in the climatic conditions of central Sudan is deteriorated. This deterioration is found significant at 50% of the stations, that is, Kadugli (South Kordufan), Damazine (Blue Nile), Nyala (South Darfur) and Wadmedani (Gezira), which are very vital areas for the agricultural production in Sudan. For instance, Wadmedani station represents the Gezira climate where the world largest singly managed irrigated scheme (Gezira scheme) exists. Consequently, the increase of aridity in this region would result in increasing the crop water requirements, considering the limited water resource, that is, Sennar dam with a storage capacity of 0.5 km^3). On the other hand, Kadugli, Damazine and Nyala stations represent the traditional rainfed agricultural areas where most of the Sudanese people favored food (sorghum) is produced. It is therefore the resulted increase inaridity is basically jeopardized food security and socioeconomic stability in central Sudan confirming the results obtained by Hamid et al. (1995) and Farah et al. (1997). Consequently, the Sudan's government became more willing to increase sorghum cultivated area under irrigated conditions at the expensive of other cash crops such as cotton (Guvele, 2002).

Detecting climate change by SI

The climatic zones in Sudan have been ascribed by with specific SI ranging values. It is important to restate that the higher the SI value is the better, that is, good climatic conditions (Table 1). Therefore, any persistent changes on those SI values for an extended period may be indicated as climatic changes. According to Table 6, all the stations experienced a decreasing trend in SI values, that is, their aridity is increased. The investigated period is 50 years, which is a persistent period, that is, IPCC in

Table 3. Mean rainfall (Rm), coefficient of variation (CV), coefficients of skewness (CS), coefficients of kurtosis (CK) and time-series period for the stations in the central Sudan.

Station	Rm (mm)	CV	CS	CK	Time period
Kadugli	662.5	0.22	0.42	0.01	1962-2009
Damazine	647.5	0.21	-0.82	0.63	1962-2005
Nyala	355.7	0.36	-0.03	-0.01	1962-1998
El Obied	315.0	0.36	0.54	0.39	1962-2005
Sennar	418.0	0.22	-0.82	0.30	1970-2006
Ed Duim	219.0	0.43	0.70	2.35	1960-1996
Gedarif	589.3	0.22	-0.06	-0.36	1962-2005
Wadmedani	280.6	0.29	0.09	0.01	1960-2005

Table 4. Mean temperature (Tm), coefficient of variation (CV), coefficients of skewness (CS), coefficients of kurtosis (CK) and time-series period for the selected stations in the central Sudan

Station	Tm (^{o}C)	CV	CS	CK	Time period
Kadugli	28.4	0.02	0.34	-0.63	1960-2010
Damazine	27.9	0.03	-1.15	2.02	1960-2010
Nyala	27.6	0.02	-0.36	-0.92	1960-2010
El Obied	26.7	0.03	0.57	-0.23	1960-2010
Sennar	28.3	0.03	-0.53	0.10	1960-2010
Ed Duim	29.3	0.02	-0.35	0.41	1960-2010
Gedarif	28.9	0.01	-0.03	-0.39	1960-2010
Wadmedani	28.8	0.03	0.14	-0.82	1960-2010

Table 5. The time series trend by Man-Kendall test for rainfall (R-MK), temperature (T-MK) and Silyaninov index (SI-MK).

Station	R-MK	T-MK	SI-MK
Kadugli	decreasing*	increasing*	decreasing**
Damazine	decreasing**	increasing*	decreasing**
Nyala	decreasing**	increasing**	decreasing**
El Obied	decreasing	increasing**	decreasing
Sennar	decreasing	increasing*	decreasing
Ed Duim	decreasing	increasing**	decreasing
Gedarif	decreasing	increasing*	decreasing
Wadmedani	decreasing*	increasing**	decreasing*

* Statistically significant at P < 0.05 and ** statistically significant at P < 0.01.

2007 suggests a decade. Thus, on the basis of the SI the central Sudan climatic zones experienced climatic changes. The significant decreasing trend in SI values were found to be 37% for Wadmedani (dry), 76% for Nyala (semi dry), 31% for Kadugli (sub humid) and 37% for Damazine (sub humid). These values suggest that aridity is increased in the central Sudan during the period of 1960 to 2010, especially in the semi dry climate, which may be sooner converted to dry conditions.

Detecting drought by SI

In the central Sudan, during the period of 1960 to 2010 the SI showed successive runs of dry years (Figure 2), which can be ascribed to the below normal rainfall. At this point it is difficult to designate those periods as drought cycles as yet there is no wide applicable definition for the term drought. For example, Abusin (1986) mentioned that in the central Sudan a drought year implies one of the

Table 6. Average changes in rainfall (mm/year), temperature (^{o}C/year) and Silyaninov index (SI) by the Theil and Sens's method.

Station	Rainfall	Temperature	SI
Kadugli	4.8	1.1	1.00
Damazine	3.8	0.4	1.00
Nyala	3.8	1.6	0.62
El Obied	0.1	2.4	0.51
Sennar	1.8	1.2	0.64
Ed Duim	2.1	1.5	0.33
Gedarif	1.1	0.5	0.87
Wadmedani	2.1	2.1	0.45

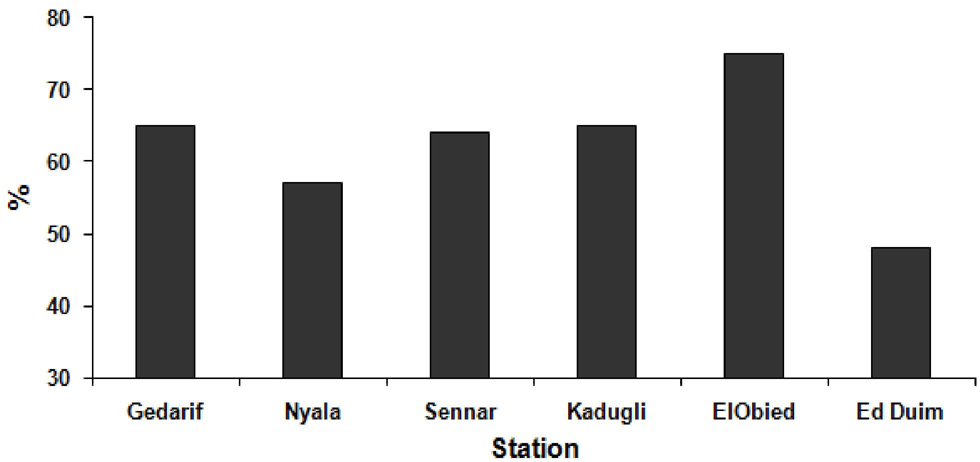

Figure 3. The performance of the Silyaninov index (SI) in detecting correctly the drought and wet years at selected stations in the central Sudan.

followings: lack of plant cover, crops failure and livestock losses, which in aggregate jeopardized the family's welfare. Thus, the drought definition will be different even between individuals of one society and from one society to another.

In this study, the power of SI in designation given year as drought or wet is evaluated using the confirmed historical events. This is firstly done without considering the drought's degree of intensity. The results suggest that generally SI is effective in detecting drought, with the exception of Gedarif and Ed Duim stations, as shown in Figure 3. The differences in detecting drought performance were largely attributed to the presence of anomalies in annual temperature. Hence, where the temperature data is anomalies-free the rainfall alone might explain much of the meteorological droughts in the central Sudan. This conclusion agrees with that of Ntale and Gan (2003) for the droughts in east African.

Hitherto, the comprehensive documentation of drought years in the central Sudan is poor. Consequently, SI is used to detect the stationary drought years. The obtained results were shown in Figure 4. It is obvious that Ed Duim and Damazine stations experienced the highest and lowest percentages of drought years of 59 and 38%, respectively. Based on the tested years, the region of central Sudan is dominated by wet conditions.

The common/regional wetted years were 1963, 1964, 1978 and 2007. The year 1984 is the only common drought year. This is revealed that rainfall of the central Sudan is characterized by its localized behavior.

According to the SPI approach, if the standardized precipitation index is continuously ≤ -1.0 there is drought event and vice versa. Therefore, each drought event has a well-defined duration (Ntale and Gan, 2003). Following the same procedure the stationary longest drought events in the central Sudan were determined (Table 7). It is clear that most of the drought events occurred during the periods of 1970 to 1990, with the exception of Damazine (1998 to 2002) and Ed Duim station (2000 to 2005). It is found also that the drought events with one year in length are dominant. Since that rainfall is found to be the dominant climatic variable in the SI estimation, the drought intensity classification scale of the SPI could be applicable to SI results. Consequently, the most detected stationary drought events in the central Sudan were classified (Table 7). It is clear that most of the drought

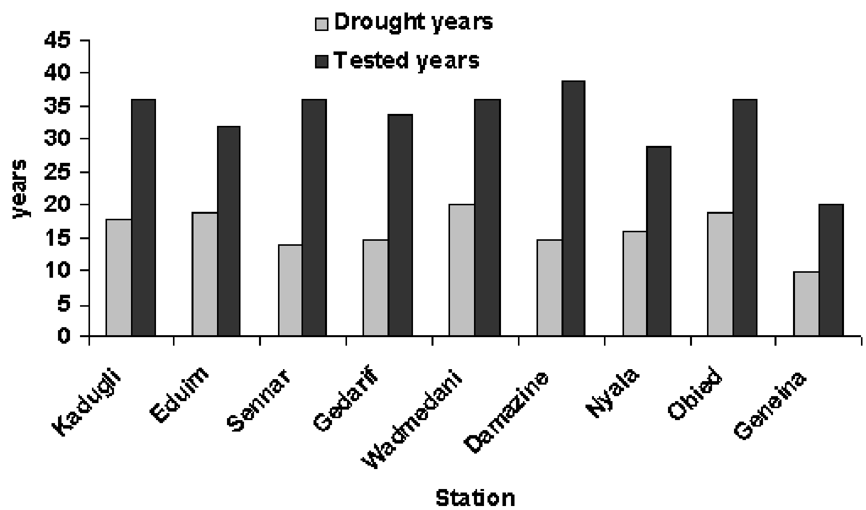

Figure 4. The drought years percentages at selected stations in the central Sudan. The trends of the standardized precipitation index, SPI (the smoothed line) and the Silyaninov index, SI (the dashed line) at selected stations in the central Sudan. The circles refer to years with different values of SPI and SI.

Table 7. The longest drought events, the driest years and their standardized Silyaninov index values (ZSI) and their drought scale at selected stations.

Station	Drought event time	Driest year	ZSI	Drought scale
Kadugli	1982-1987	2001	-1.61	Severe
Damazine	1998-2002	2004	-2.20	Extreme
Nyala	1982-1987	1984	-1.80	Severe
El Obied	1982-1985	1982	-1.95	Severe
Sennar	1965-1970	1981	-2.18	Extreme
Ed Duim	2000-2005	1984	-1.93	Severe
Gedarif	1970-1977	1984	-1.83	Severe
Wadmedani	1966-1970	2000	-1.50	Severe

cycles can be classified as severe (-1.5 ≥ SI ≥ -1.99), with the exception of Damazine and Sennar stations, which show extreme drought events (SI ≤ -2.0). The use of regional mean in the central Sudan is found questionable and deceptive. For instance, on the basis of the regional rainfall average the central Sudan experienced a long-term drought cycle of 30 (1972 to 2002) as shown in Figure 5, which is unrealistic. Thus, the use of regional average in central sudan is not recommended.

Relationships of natural vegetation cover with rainfall, temperature and SI

Most of the obtained NDVI values were found to be below the general average for the period of 2000 – 2010 (Figures 6 and 7). This is attributed to the deterioration in the climatic conditions of the central Sudan, agreeing with the results of the Vicente et al. (2006) who found that aridity has caused a general decreasing of NDVI and increasing of coefficient of variation, in Spain. On the other hand, the result disagreed with results of Hermann et al. (2005) who indicated that there is a seasonal increasing trend in the greenness of the African Sahel region using the NDVI time series analysis (1982-2003).

Forestry system (90 million hectares, Mha) is the largest vegetation cover in Sudan (FAO, 2006). Its area however, is diminished by 3% during the period of 1976-1990 (Elbashir, 1994). Oldeman et al. (1991) stated that about 5 Mha of land in Africa as lost its original biotic functions due to degradation, to a level that their rehabilitation is economically been difficult. In Sudan, forestry system has an appreciated potential economic values that is, gum Arabic production, a sustainable timber industry, wildlife tourism, woods, etc (Glover, 2005). Thus, one of the steps that can be immediately taken regarding forest rehabilitation is the re-enforcement

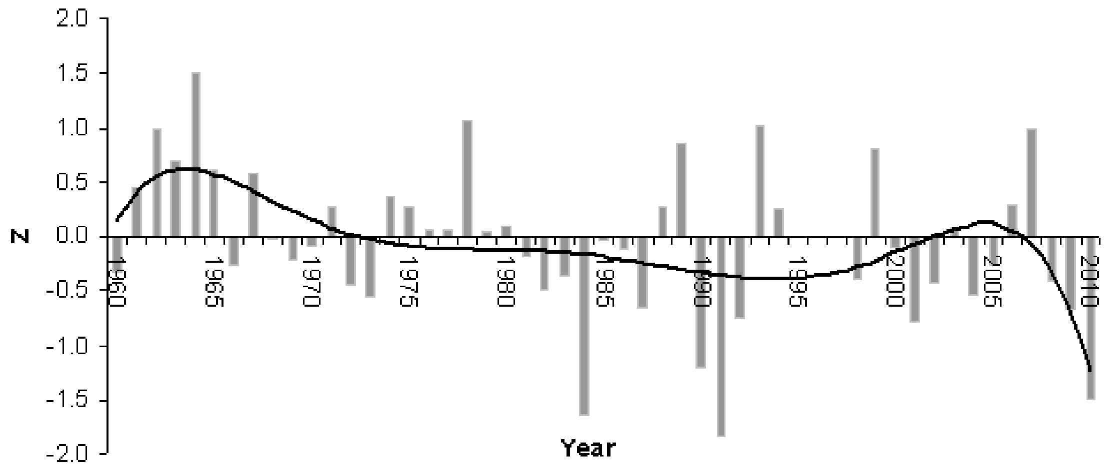

Figure 5. The standardized regional SI value.

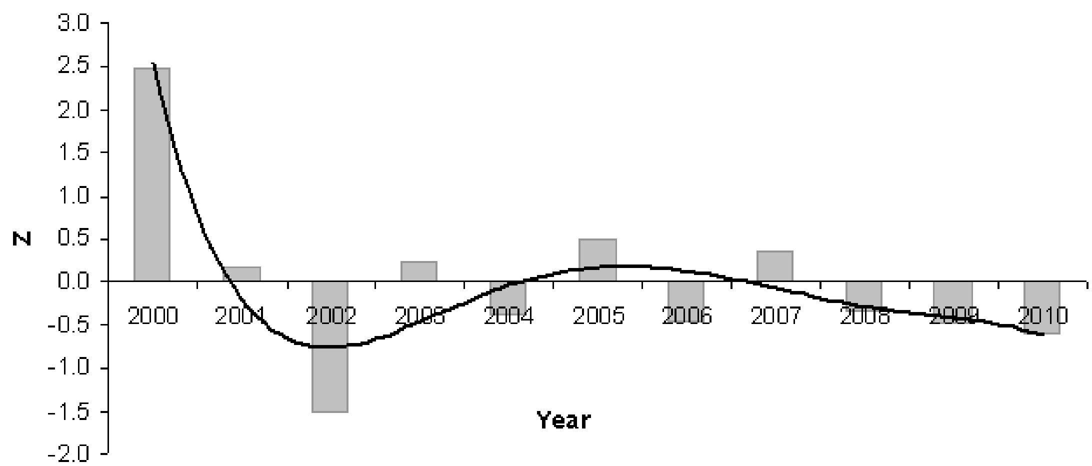

Figure 6. The standardized values of the NDVI for the forest, Damazine area. The smoothed line is the trend of NDVI

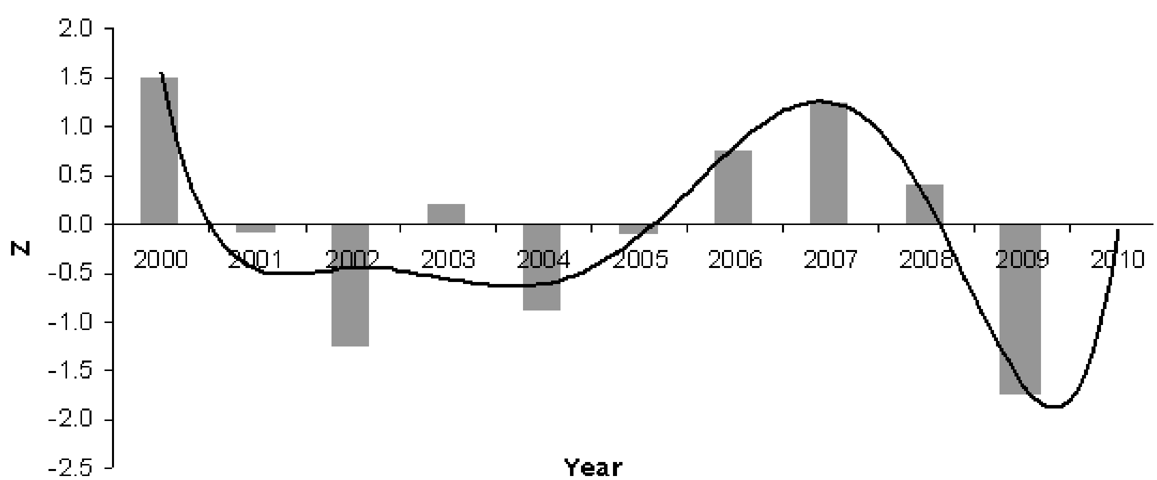

Figure 7. The standardized values of the NDVI for the forest, Gedarif area. The smoothed line is the trend of NDVI.

of the 10% law that is, set aside 10% of the farmer's land for forest production. Also, there is an urgent need for reforestation plans, which can be defined as the establishment of tree crops on deforested or cleared land, either on land previously degraded by agriculture, mining, or other activity, or on lands cleared of native vegetation specifically for the purpose of plantation establishment (Bowyer, 2001). However, care should be taken as some studies showed that improper forestation plans were lead to soil compaction, erosion and depletion of soil organic matter and thus degradation of physical and nutritional properties of soil (Bowyer, 2001). Thus, the good vegetation restoring plan needs the suitable vegetation to be re-stored in its right place. This required in-depth studies, e.g. studies on soil moisture variability are important since soil moisture is crucial to ecosystem restoration (Ma et al., 2004).

The detected vegetation-ecoclimatic relationships between NDVI-rainfall, NDVI-temperature and NDVI-SI were found nonlinear (exponential) under both the semi dry and sub humid climates. This is in conformity with the results of Vicente et al. (2006) who suggested a non-linear relationship between aridity and NDVI. Hermann et al. (2005) however reported a direct relationship between NDVI and rainfall at a threshold below 1000 mm per year, in the African Sahel zone.

Generally, the resulted Pearson correlations in the semi dry climate were observed higher than that of the sub humid. They were 0.88 for NDVI-temperature, 0.79 for NDVI-rainfall and 0.81 for NDVI-SI in the semi dry climate compared with 0.85, 0.62 and 0.61 for the semi dry climate, respectively. Because temperature is an indirect indicator for energy available for the plant development a strong relation between NDVI and temperature is anticipated (Tan, 2007). On the tested relations, NDVI-temperature was the highest; but it was statistically insignificant, which is attributed to the minimum variation in the annual temperature values (CV ≈ 3%). On the other hand, the relations NDVI- rainfall and NDVI- SI were found significant at 0.05 and 0.0005 levels of significance for sub humid and semi dry climates, respectively. It is worth mentioning that the slope of the relation NDVI-temperature is found negative and the opposite holds true for the relations NDVI-rainfall and NDVI-SI. This is indicated that the continued increasing in temperature may degrade the greenness of the forestry system in Sudan. Accordingly, rainfall is found to be the most significant climatic variable that affects the dynamics of the vegetation cover in the central Sudan.

Conclusion

Most of the livelihood generations are climate depended in the central Sudan. This study concerned on providing simple and cost effective approach for detecting climate change, drought and vegetation dynamics in the central Sudan using Silyaninov index (SI) and the normalized difference vegetation index (NDVI). Both indices showed good results. The most important result is that drought disturbed the climatic conditions of central Sudan, if the current trend of degradation is continued sooner the semi arid zone would experience arid conditions and the latter would change to desert conditions. Accordingly, the agricultural sector/food security will not sustain without irrigation, which is limited by water resources availability.

The accuracy of the SI results depends on two factors; the quality of inputs (rainfall and temperature) and availability of data (length of record). The former found to be poor since the homogeneity of the datasets were questionable. The length of record was disrupted mainly because of direct drought consequences (civil unrest) and fund issues as most of the meteorological stations in central Sudan were out of service since 1980s. This entails rehabilitation projects for the meteorological stations as well as capacity building programs.

REFERENCES

Abusin M (1986). Man's socio-economic response to drought in the White Nile. In: Rural Development in White Nile Province, Sudan (eds H. R. J. Davies). United Nations University Press, Tokyo, Japan.

Adam H (2002). Agroclimatology. University of Gezira Press. Wadmedani, Sudan.

Allen R, Pereira L, Raes D, Smith M (1998). Crop evapotranspiration. Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56. Rome, Italy.

Arora V (2002). The use of the aridity index to assess climate changeeffect on annual runoff. J. Hydr. 265:164-177. http://dx.doi.org/10.1016/S0022-1694(02)00101-4

Ayoub A (1998). Extent, severity and causative factors of land degradation in the Sudan. J. Arid Environ. 38:397-409. http://dx.doi.org/10.1006/jare.1997.0346

Ayoub A (1999). Land degradation, rainfall variability and food production in the Sahelian zone of the Sudan. J. Land Degrad. Dev. 10:489-500.http://dx.doi.org/10.1002/(SICI)1099-145X(199909/10)10:5<489::AID-LDR336>3.0.CO;2-U

Basistha A, Arya D, Goel N (2009). Analysis of historical changes in rainfall in the Indian Himalayas. Int. J. Clim. 29:555-572. http://dx.doi.org/10.1002/joc.1706

Bastiaanssen W, Ahmad M, Tahir Z (2003). Upscaling water productivity in irrigated agriculture using remote-sensing and GIS technologies. In: Water productivity in agriculture: Limits and Opportunities for Improvement (eds J.W. Kijne, R. Barker and D. Molden). CAB International 2003.

Bates B, Kundzewicz Z, Wu S, Palutikof J (2008). Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva.

Bowyer J (2001). Environmental implications of wood production in intensively managed plantations. J. Wood Fiber Sci. 33(3):318-333

Burn D, Hag Elnur M (2002). Detection of hydrologic trends and variability. J. Hydrol. 255:107-122. http://dx.doi.org/10.1016/S0022-1694(01)00514-5

Burton I, Lim B (2005). Achieving adequate adaptation in agriculture. J. Clim. Change. 70:191-200. http://dx.doi.org/10.1007/s10584-005-5942-z

Challinor A, Wheeler T, Garforth C, Craufurd P, Kassam A (2007). Assessing the vulnerability of food crop systems in Africa to climate change. J. Clim. Change 83:381-399. http://dx.doi.org/10.1007/s10584-007-9249-0

Clark C, Schkade L (1969). Statistical methods for business decisions. South Western Publishing Co. New York.

Elbashir A (1994). Population and Environmental Degradation in the Sudanese agriculture and forestry. Proceedings of the Khartoum Nile

2002 Conference 29th January- 1st February 1994. PMid:7756939
Eldredge E, Khalil S, Nicholds N, Abdallah A, Rydjeski D (1988). Changing rainfall patterns in western Sudan. Int. J. Clim. 8:45-53. http://dx.doi.org/10.1002/joc.3370080105
El Fadni O (1998). Climatic zones in Sudan. M. Sc. thesis. Faculty of Agriculture Umdurman University, Sudan.
Elhag M, Walker S (2009) Impact of climate variability on vegetative cover in the Butana area of Sudan. Afr. J. Ecol. 47:11-16. http://dx.doi.org/10.1111/j.1365-2028.2008.01044.x
Farah S, Salih A, Taha A, Ali Z, Ali A (1997). Grain sorghum response to supplementary irrigations under post-rainy season conditions. J. Agric. Water Manage. 33:31-41. http://dx.doi.org/10.1016/S0378-3774(96)01283-8
FAO (2010). Crop production and food security assessment for the northern states of the Sudan. Assessment mission report 2009/2010. Rome, Italy.
FAO (2006). Fertilizer use by crop in the Sudan. Land and Plant nutrition and management service. Land and Water Development division, Rome, Italy.
Gitay H, Suarez A, Watson R, Dokken D (2002). Climate change and biodiversity. IPCC Technical Paper 5.
Guvele CA (2002). Gains from crop diversification in the Sudan Gezira scheme. J. Agri. Syst. 70:319-333. http://dx.doi.org/10.1016/S0308-521X(01)00030-0
Hamid F, Yousif G, Mohamed I (1995). Potentials of the Sudan's irrigated sector in cereals grain production: Analysis of various policy options. J. Agric. Syst. 48:457-483. http://dx.doi.org/10.1016/0308-521X(94)00026-H
Hulme M (1986). Secular changes in wet season structure in central Sudan. J. Arid Environ. Academic Press Inc. (London) Limited.
Hulme M, Viner D (1998). A climate change scenario for the tropics. Clim. Change. 39:145-176. http://dx.doi.org/10.1023/A:1005376007729
Hulme M (2001). Climatic perspectives on Sahelian desiccation: 1973-1998. Global. Environ. Change. 11:19-29. http://dx.doi.org/10.1016/S0959-3780(00)00042-X
IPCC (2007). Climate Change, Synthesis Report. The 4th Assessment Report of the Intergovernmental Panel on Climate Change, Valencia, Spain.
Lioubimtseva E, Cole R, Adams J, Kapustin G (2005). Impacts of climate and land-cover changes in arid lands of Central Asia. J. Arid Environ. 62:285-308. http://dx.doi.org/10.1016/j.jaridenv.2004.11.005
Logan K, Brunsell N, Jones A, Feddema J (2010). Assessing spatiotemporal variability of drought in the U.S. central plains. J. Arid Environ. 74:247-255. http://dx.doi.org/10.1016/j.jaridenv.2009.08.008
Luo Y, Liu S, Fu S, Liu J, Wang G, Zhou G (2008). Trends of precipitation in Beijiang river basin, Guangdong province, China. J. Hydr. Proc. 22:2377-2386 http://dx.doi.org/10.1002/hyp.6801
Ma K, Fu B, Liu S, Guan W, Liu G, Lu Y, Anand M (2004). Multiple-scale soil moisture distribution and its implications for ecosystem restoration in an arid river valley, China. J. Land Dev. 15:75-85.
Mati B (2005). An overview of water and soil nutrient management under small holder rain-fed agriculture in east Africa. Working Paper No. 105. Colombo, Sri Lanka: International Water Management Institute (IWMI).
Mavromatis T (2010). Use of drought indices in climate change impact assessment studies: an application to Greece. Int. J. Clim. 30:1336-1348
Modarres R, Silva V (2007). Rainfall trends in arid and semi arid regions of Iran. J. Arid Environ. 70:344-355 http://dx.doi.org/10.1016/j.jaridenv.2006.12.024
Morid S, Smakhtin V, Moghaddasi M (2006). Comparison of seven meteorological indices for drought monitoring in Iran. Int. J. Clim. 26:971–985 http://dx.doi.org/10.1002/joc.1264
Mpelasoka F, Hennessy K, Jones R, Bates B (2008). Comparison of suitable drought indices for climate change impacts assessment over Australia towards resource management. Int. J. Clim. 28:1283-1292. http://dx.doi.org/10.1002/joc.1649
Nasri M, Modarres R (2009). Dry spell analysis of Isfahan province, Iran. Int. J. Clim. 29:1430-1438. http://dx.doi.org/10.1002/joc.1805
Ntale H, Gan T (2003). Drought indices and their application to east Africa. Int. J. Clim. 23:1335-1357. http://dx.doi.org/10.1002/joc.931
Oldeman L, Hakkeling R, Sombroek W (1991). World Map of the Status of Human-induced Soil Degradation: An Explanatory Note. ISRIC-UNEP Report, Netherlands.
Oladipo E (1985). A comparative analysis of three meteorological drought indices. J. Clim. 5:655-664. http://dx.doi.org/10.1002/joc.3370050607
Omuto C, Shrestha D (2007). Remote sensing techniques for rapid detection of soil physical degradation. Int. J. Rem. Sens. 28(21):4785-4805 http://dx.doi.org/10.1080/01431160701260357
Osman Y, Shamseldin A (2002). Qualitative rainfall prediction models for central Sudan and southern Sudan using Elnino-Southern Oscillation and Indian Ocean sea surface temperature indices. Int. J. Clim. 22:1861-1878 http://dx.doi.org/10.1002/joc.860
Rodrigo F, Esteban P, Vazquez D, Diez Y (1999). A 500-year precipitation record in Southern Spain. Int. J. Clim. 19:1233-1253. http://dx.doi.org/10.1002/(SICI)1097-0088(199909)19:11<1233::AID-JOC413>3.0.CO;2-L
Sivakumar M, Das H, Brunini O (2005). Impacts of present and future climate variability and change on agriculture and forestry in the arid and semi arid tropics. Clim. Change. 70:31-72. http://dx.doi.org/10.1007/s10584-005-5937-9
Smith M, Koren V, Zhang Z, Reed S, Pan, Mored F (2004). Runoff response to spatial variability in precipitation: An analysis of observed data. J. Hydrol. 298:267-286. http://dx.doi.org/10.1016/j.jhydrol.2004.03.039
Tan S (2007). The influence of temperature and precipitation climate regimes on vegetation dynamics in the US Great Plains: A satellite bioclimatology case study'. Int. J. Rem. Sens. 28(22):4947-4966. http://dx.doi.org/10.1080/01431160701264268
Teklu T, Braun J, Zaki S (1991). Drought and Famine relationships in Sudan: Policy implications. Research Report No. 88. International Food Policy Research Institute.
Tilahun K (2006). Analysis of rainfall climate and evapo-transpiration in arid and semi-arid regions of Ethiopia using data over the last half a century. J. Arid Environ. 64:474-487
Vicente-Serrano S, Cuadrat-Prats J, Romod A (2006). Aridity influence on vegetation patterns in the middle Ebro Valley (Spain): Evaluation by means of AVHRR images and climate interpolation techniques. J. Arid Environ. 66:353-375. http://dx.doi.org/10.1016/j.jaridenv.2005.10.021
Wu H, Hayes M, Wilhite D, Svoboda M (2005). The effect of the length of record on the standardized precipitation index calculation. Int. J. Clim. 25:505-520. http://dx.doi.org/10.1002/joc.1142
Xu Z, Liu Z, Fu G, Chen Y (2010). Trends of major hydroclimatic variables in the Tarim River basin during the past 50 years. J. Arid Environ. 74:256-267. http://dx.doi.org/10.1016/j.jaridenv.2009.08.014
Yue S, Pilon P, Cavadias G (2002). Power of Mann-Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. J. Hydrol. 259:254-271. http://dx.doi.org/10.1016/S0022-1694(01)00594-7
Yue S, Wang C (2004). The Mann-Kendall Test Modified by Effective Sample Size to Detect Trend in Serially Correlated Hydrological Series. Water Res. Manage. 18:201-218. http://dx.doi.org/10.1023/B:WARM.0000043140.61082.60