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Monitoring Drought in Central Sudan by Using Combined Drought Index

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Abstract: Drought is an extended period during which water availability and accessibility in a given ecosystem at a given time and place is below normal, due to uneven temporal distribution of rainfall with long, below-average periods, high temperatures and prolonged, above-average hot periods, low soil moisture content and uneven temporal distribution of soil moisture, high velocity wind. The aim of this paper is to investigate the ability of the Combined Drought Index (CDI), to monitor the drought persist in central Sudan. The CDI is a new drought index develop by FAO-SAWMALIA aim to incorporates and reflects the combined effect of the drought-creating parameters; rainfall deficits; Temperature component and NDVI deficits and deficit persistence. The CDI was applied for five stations in central Sudan (Khartoum, Wad Medani, Sennar, Kosti and Dueim). The analysis covered the period from 1982 to 2011. The CDI analysis for Khartoum station shows repeated cycles of severe drought followed by extreme drought since 1984, this is tended to occur every two years, since 1987.while the last four years showed successive severe drought events. While Wad Medani station showed a rapid fluctuation between mild and extreme drought with few years with no drought since 1991. The last 21 years (1991-2011) there is an extreme drought every two years. Sennar station experienced sever to extreme drought from1981 to 1986 followed by three years (1987- 1989) of moderate and mild drought events. Since 2003 the severe drought turned into extreme drought lasted after 2007, while in 2009-2010 there is severe drought. Kosti station showed clear fluctuations between mild and severe drought during the analysis period with steady occurrence of severe drought in the last four years (from 2008 -2011). Unlike the others; Dueim showed a stable fluctuation between mild and moderate drought with eleven (11) years with extreme drought in the course of the period of the analysis. The comparison of the official drought records with CDI calculations show very good results of coincidence.

Key words: Combined drought index, Temperature drought index, Vegetation drought index, Central Sudan

INTRODUCTION

Droughts are unique in that unlike floods, earthquakes, or hurricanes; during which violent events of relatively short duration occur, droughts are like a cancer on the land that seems to have no recognized beginning [1]. Droughts covering a few hundred square kilometres do exist but these are usually of limited duration and modest severity. There is so many definitions of drought phenomena, according to Wilhite and Glantz [2] their four commonly type of drought "Meteorological; Agricultural or ecological; Hydrological and Socio-economicdrought", while Kallis, [3] defined drought as ''admixtures of climatic, hydrological, environmental, socioeconomic and cultural forces''.

The climate of Sudan has been changing in many aspects, including reduction of rainfall [4, 5], the trend of warmth and dryness has a strong association [6, 7]. As many other Sahelian African countries, Sudan is a drought prone area. Drought events have become more recurrent in recent decades during early to mid-1970s, mid-1980s, early 1990s and early 2000s [7]. Due to the dependence on water resources and soil moisture reserves during various stages of crop growth, agriculture and natural vegetation cover is often the first sector to be affected by the onset of drought [8]. There are many types of drought monitoring indices exist in the professional literature at present [9]. These indices mainly based on: Water balance calculation and Statistical indices based on time series analysis. Most statistical

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indices are based on one or occasionally seldom two parameters, mostly rainfall and sometimes temperature. To date, the most commonly used drought indices in this category include the Standardized Precipitation Index (SPI), the Precipitation Decile Index and etc. Drought events are increasing, at least in Africa and there is naturally more and more discussion about their mitigation and management. At the same time, the existing drought indices do not meet the special requirements of African drought managers. Quiring [9] stated that "Overall, no single index can represent all aspects of meteorological drought". Who further identified three main aspects for a drought to be tractable, namely easiness of calculation, availability of data required and usefulness. Therefore, the Combined Drought Index (CDI) is a new drought index develop by FAO-SAWMALIA aim to incorporates and reflects the combined effect of the drought-creating parameters; A precipitation component which considers rainfall deficits and persistence of dryness; A temperature component which considers temperature excesses and persistence of high temperatures; A soil moisture component which considers soil moisture deficit and persistence of dry soil conditions – because of limitations in soil moisture observations this is approximated by NDVI deficits and deficit persistence. It can be based on 10-day or monthly observations and cover seasonal, annual or longer periods, also it can be used in data-scarce environments, with data gaps in the observed series and gives the flexibility to change the time units (interest periods) and lengths of analysis to fit various geographic areas and climate characteristics, to analyze various scenarios. The aim of this study is to investigate the ability of the Combined Drought Index (CDI), to monitor the drought persist and severity in central Sudan Materials and Methods.

MATERIALS AND METHODS

Study Area: This study focused on the central Sudan, which includes four states, Khartoum; Al Gezira; Sennar and White Nile, with total area of about 113,770 km^2 and total population of about 11,865,247 according to 2008 population professional census. The study area contains five meteorological stations (*Khartoum, Wad Medani, Dueim, Kosti and Sennar*) (Figure 1).

Data and Data Analysis: Meteorological data was obtained from Sudan Meteorological Authority (*SMA*), which is including rainfall, maximum temperature and NDVI for the period of study (1981-2011) for the five stations under study. Rainfall and maximum temperature data cover all the period of the study, while NDVI started from 1982 to 2011, with in continuity of 3 years (2004,2005 and 2006) in NDVI data for the five stations. All the data used in this study is quality controlled. For the analysis purposes CDI software and MS Excel were used.

Method: Combined Drought Index (CDI) approach considers drought as a combination of three individual drought indices.

- The precipitation Drought Index (PDI).
- The Temperature Drought Index (TDI).
- The Vegetation Drought Index (VDI).

The equation of calculating the precipitation drought index (PDI), the temperature drought index (TDI) and the vegetation drought index (VDI) for year *i* and time unit (dekad/month) *m* are given in the following equations:

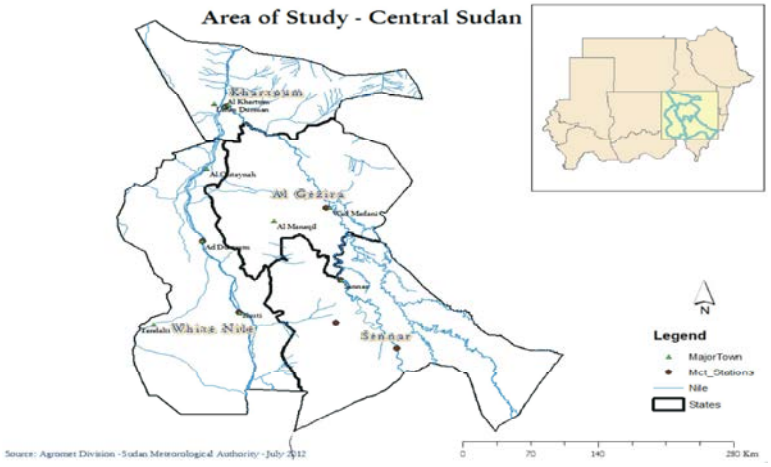

Fig. 1: Analysis of PDI, TDI and VDI values

$$PDI_{i,m} = \frac{\frac{1}{IP}\sum_{J=0}^{IP_{-1}} P^*_{i,(m-j)}}{\frac{1}{(n*IP)}\sum_{k=1}^{n}[\sum_{J=0}^{IP_{-1}} P^*_{(m-j),k}]} * \sqrt{\left[\frac{RL_{m,i}^{(P^*)}}{\frac{1}{n}\sum_{k=1}^{n}\left(RL_{m,k}^{(P^*)}\right)}\right]} \quad (1)$$

$$VDI_{i,m} = \frac{\frac{1}{IP}\sum_{j=0}^{IP_{-1}} NDVI^*_{i,(m-j)}}{\frac{1}{(n*IP)}\sum_{k=1}^{n}[\sum_{j=0}^{IP_{-1}} NDVI^*_{(m-j),k}]} * \sqrt{\left[\frac{RL_{m,i}^{(NDVI^*)}}{\frac{1}{n}\sum_{k=1}^{n}\left(RL_{m,k}^{(NDVI^*)}\right)}\right]} \quad (2)$$

$$TDI_{i,m} = \frac{\frac{1}{IP}\sum_{j=0}^{IP_{-1}} P^*_{i,(m-j)}}{\frac{1}{(n*IP)}\sum_{k=1}^{n}[\sum_{j=0}^{IP_{-1}} T^*_{(m-j),k}]} * \sqrt{\left[\frac{RL_{m,i}^{(T^*)}}{\frac{1}{n}\sum_{k=1}^{n}\left(RL_{m,k}^{(T^*)}\right)}\right]} \quad (3)$$

where:

P* : The modified monthly or 10-day precipitation amount,

T* : Modified monthly or 10-day average Temperature,

NDVI* : Modified monthly or 10-day average normalized Difference Vegetation Index,

IP : Interest period (e.g. 3,4,5, … dekads or months),

RL(P) : (run-length) is maximum number of successive dekads or months below long term average rainfall in the interest period,

RL(T) : Maximum number of successive dekads or months above long term average temperature,

RL (NDVI) : Maximum number of successive dekads or months below long term average NDVI in the IP,

n : Number of years with relevant data,

J : Summation running parameter covering the IP and

K : Summation parameter covering the years where relevant data are available.

The calculation of the drought index in simple words can be expressed as:

$$\text{Drought Index} = \frac{\textit{Actual average for IP}}{\textit{LTM for IP}} * \sqrt{\frac{\textit{Actual length of continous deficit / excess in the IP}}{\textit{LTM length of continous deficit / excess in the IP}}} \quad (4)$$

where:

IP : The interest period,

LTM : The long term average,

Deficit : Applies to rainfall and NDVI,

Excess : Applies to temperature.

Equations (1), (2) and (3) use modified rainfall, modified NDVI and modified temperature data. The original data series would work well in many cases, for the calculation and input standardization purposes it is recommended to use the modified observation series. One of the purposes of the modification is to avoid dividing by zero in certain cases, with rainfall mostly in countries with a deficit, long dry season. The purpose is to have a similar range of drought index values. The modification can be done by shifting the x coordinate axis to convenient value as in equ (5). The modification only serves calculation purposes; it does not change the nature of the data series or that of the results in any way:

$$\begin{aligned} T^* &= (T_{max} + 1) - T \\ RL^* &= (Rlmax + 1) - RL \\ NDVI^* &= NDVI - (NDVI_{min} - 0.01) \end{aligned} \quad (5)$$

where P, T and NDVI are the original precipitation, temperature and NDVI values and RL is the original run-length.

Calculation of the Combined Drought Index (CDI): CDI computed as the weighted average of the precipitation, the temperature and the soil moisture drought indices. According to the difficulties of accessibility to soil moisture observation data, the values of the soil moisture drought index are approximated by the vegetation drought index. CDI is given by the following equation:

$$CDI_{i,m} = w_{PDI} * PDI_{i,m} + w_{TDI} * TDI_{i,m} + w_{VDI} * VDI_{i,m} \quad (6)$$

w: the weight of the individual drought index.

It is recommended to use 50% weight for PDI and 25-25&% weight for TDI and VDI.

Table 1: Combined Drought Index (CDI) Categories

CDI value	Drought Severity
> 1.0	No drought
1.0 - 0.8	Mild
0.8 - 0.6	Moderate
0.6 - 0.4	Severe
< 0.4	Extreme

Combined Drought Index (CDI) Values: Combined Drought Index (CDI) has five categories define the drought severity, which range from < 0.4 to > 1.0; the following table shows the index values, related categories and associated color code:

RESULTS AND DISCUSSION

Figure 1 (a, b, c, d, e) presents the analysis of PDI, TDI and VDI of time series data of rainfall, Temperature and NDVI for five weather stations in central Sudan. There is decreasing trend of PDI, TDI and VDI at Wad Medani, Sennar, Kosti and Dueim. While, the situation is differ at Khartoum Station there is increasing trend of PDI and VDI which indicated strong relation between vegetation cover and rainfall at Khartoum area. The smallest values of the three indices indicate a severe drought condition.

The results showed that the CDI for Khartoum Station clearly pick up the famous drought and famine period in Sudan that was 1984/85, where it reached severe and moderate levels (Fig. 2). The two periods with two successive years of mild to severe drought were occurred in 1983/1984 and 1990/1991. CDI also showed that during the study period there is 11 years of severe drought and 20 years out of 31 years with no drought in Khartoum Station. In spite of a rapid fluctuation of no drought to severe drought, there is no clear cycle of drought shown by depicting CDI for Khartoum station.

Fig. 3 illustrated the results of the drought severity of Wad Medani station CDI valuesrange between no drought and severe drought from 1982 - 1989, in 1990 and 1991 and 2000 CDI reached the extreme category. The period from 1994 to 1999 also well as period from 2001 to 2003 CDI showed fluctuations between no drought and moderate category. There is severe category during 2008 and 2009.

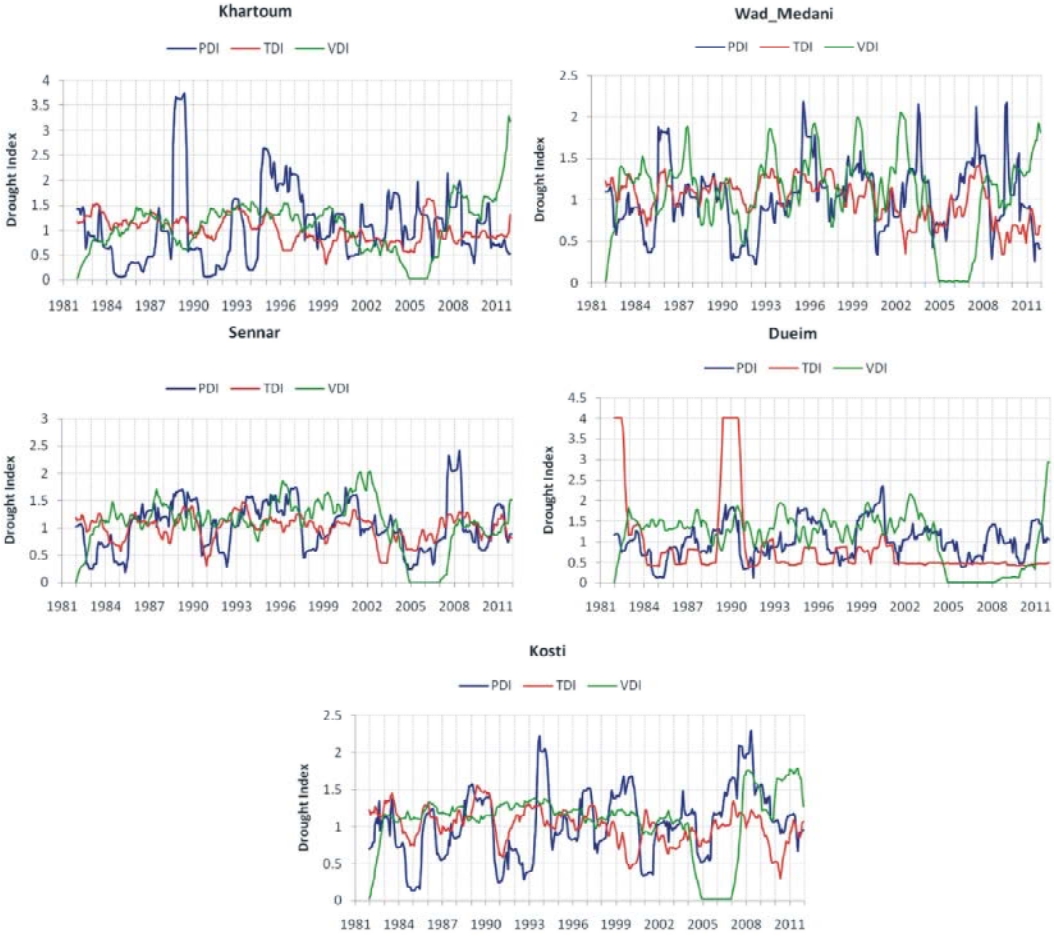

Fig. 1: Showing the analysis of PDI , TDI and VDI values

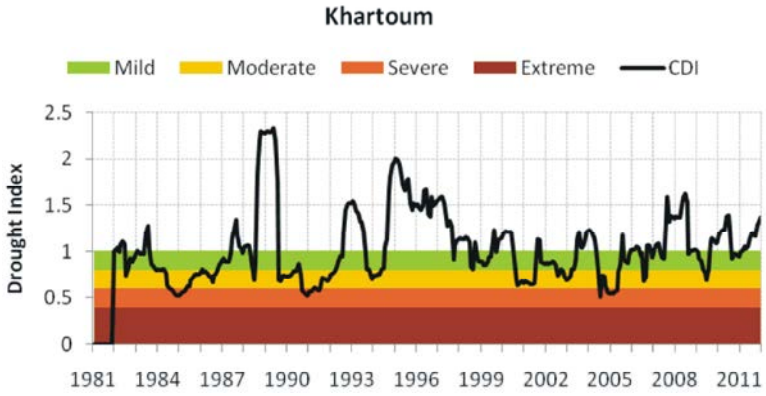

Fig. 2: Categories of Combined Drought Index during the period (1981 - 2011) for Khartoum station

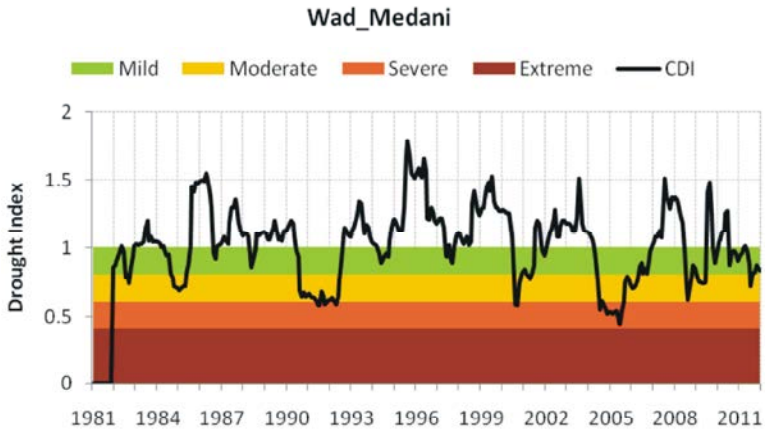

Fig. 3: Categories of Combined Drought Index during the period (1981 - 2011) for Wad Medani station

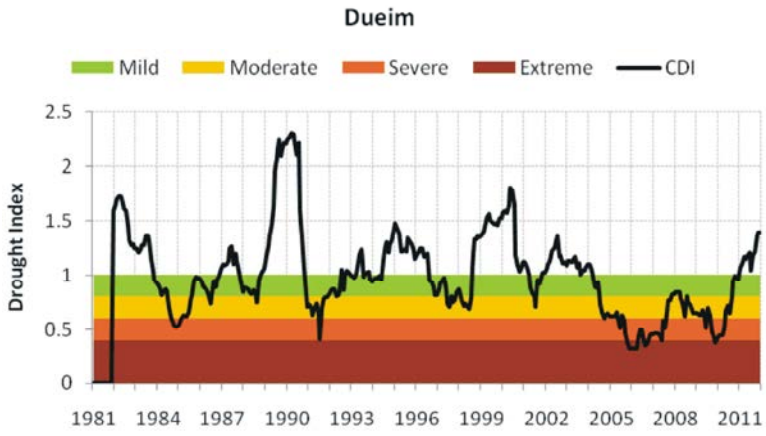

Fig. 4: Categories of Combined Drought Index during the period (1981 - 2011) for Duiem station

In Dueim station the analysis showed that during period from 1982 to 2004 their only two years with severe drought (1985, 1991), after these period their extreme drought in 2005, 2006, 2007 and 2009 (Fig. 4).

Fig. 5 illustrated that there is severe drought in 1984 and 1986. During 1987, 1988 and 1889 the analysis shows that there is a positive trend towards no drought category. The period of 1992 to 1999 the CDI was fluctuate between no drought and moderate categories. From 2000 to 2003 the CDI went to the severe category. From 2007 to 2009 the index showed no drought combined with moderate category during the dries periods of these years. 2010 and 2011 brought the CDI to the severe category.

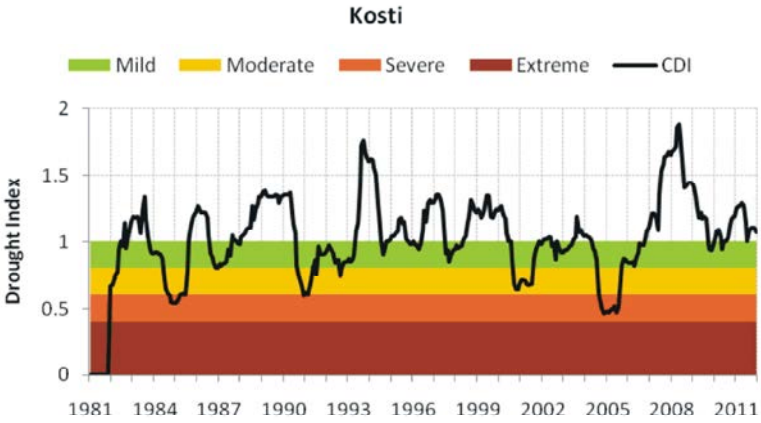

Fig. 5: Categories of Combined Drought Index during the period (1981 - 2011) for Kosti station

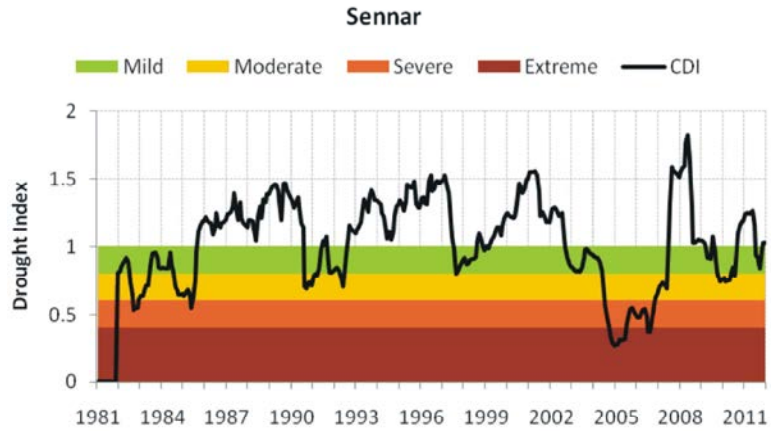

Fig. 6: Categories of Combined Drought Index during the period (1981 - 2011) for Sennar station.

Figure 6 showed the fluctuation of the CDI for Sennar Station as a result of the other three indices (ODI, TDI and VDI). CDI clearly showed the famous drought and famine period in Sudan that was 1984, where it reached the extreme level; there is very hot summer in 1986 which reflected in severe CDI level during April-June period. The period from1987 to 1990 showed mild to moderate drought.

1988, 19090 and 1992 bring the CDI to Extreme level again as a result of shortage of rainfall. This cycle of extreme drought was repeated during 1990 and 1992. The situation was getting better as the CDI reached the mild level in 1997. Extreme level was registered in 1998 followed by two good years with moderate and mild level 1999 and 2000, respectively. The drought cycle began in 2001 with severe level and developed to extreme level in 2003 and 2005. CDI raised again in 2006 followed by severe level in 2007. In 2008 CDI was above 2 which indicate no drought but this followed by extreme drought in 2009 and high CDI in 2010 and severe drought in 2011.

It seems that the frequencies of drought occurrence was shrining. The study period started with no drought in 1982 and 1983 followed by one year with extreme drought in 1984 and the situation was fully recovered in 2005 where was no drought.

Steady recovered period were noted from 1995 to 1997 and from 1999 and 2001. The period from 2003 to 2010 the CDI showed continuous drought ranging from moderate to severe except 2008 which reached no drought category.

However, the rainfall sand temperature were reasonable but the in continuity in NDVI time series for the years 2004, 2005 and 2006 in this station brought the CDI down to extreme category during this years.

CONCLUSIONS

Combined Drought Index (CDI) has been applied to five stations in central Sudan spread in four states (Khartoum, Al Gezira, White Nile and Sennar) for the period from 1982 to 2011. The Combined Drought Index

indicate that the last 21 years (1991-2011) showed that there is an extreme drought every two years. Sennar experienced sever to extreme drought from1981 to 1986 followed by three years (1987- 1989) of moderate and mild drought events. Since 2003 the severe drought turned into extreme drought lasted after 2007.Analysis of Kosti showed clear fluctuations between mild and severe drought during the analysis period with steady occurrence of severe drought in the last four years (from 2008 -2011).

Dueim showed a stable fluctuation between mild and moderate drought with eleven years with extreme drought in the course of the period of the analysis.

Considering the drought event on 1984, the Combined Drought Index (CDI) succeeded to show concise results over the study area. The results obtained from the calculations of CDI for the central Sudan confirmed the usability of CDI calculator to study drought over Sudan using long time series. Also, CDI can be used as a tool of drought monitoring by applying analysis for shorter periods like Dekads or longer as seasons.

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