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Analysis of the Drought Impact as an Extreme Climatic Event in Sudan

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Abstract

This study aimed to investigate drought as an extreme climatic event in Sudan by utilizing the Anomaly and Standard Precipitation Index (SPI). This research employed high-resolution Climate Hazards Group Infrared Precipitation with Station (CHIRPS) data to analyze the temporal and spatial distribution of rainfall in Sudan from 2001 to 2015. Notably, the analysis compared the annual average precipitation to specific drought events and calculated the Standardized Precipitation Index (SPI). The results indicate a striking frequency of drought occurrence in Sudan, with SPI values suggesting similarities between drought and wet years. It is recommended to compute the SPI for individual stations rather than rely solely on area averages. Despite the comparable SPI values between the drought and wet years, this study emphasizes the profound impact of drought as a recurring phenomenon in Sudan. These findings emphasize the urgent need for proactive drought management and mitigation strategies in Sudan to effectively address the consequences of this climatic challenge.

Keywords

CHIRPS, SPI, Anomaly, Rainfall, Aridity

1. Introduction

In areas that depend heavily on agriculture, drought is a complicated phenomenon that affects socioeconomic and agricultural activities in major ways (Hao et al., 2018). According to Tate & Gustard, (2000), droughts are long-lasting natural occurrences that are linked to severe water shortages. Dodangeh et al. (2017) point out that the complexity of drought conditions prevents a full understanding of them. Even though it can be difficult to forecast extreme events like droughts, it is essential that we strengthen our capacity to both effectively manage future extreme events and adapt to the detrimental effects of climate change. This necessitates a precise and exhaustive evaluation of the features of the drought. Even though it can be challenging to comprehend drought conditions, they can be tracked and described. Long-term data with suitable spatial and temporal coverage on precipitation, temperature, evapotranspiration, land cover, soil moisture, and river flows are needed to characterize a drought. Datasets on rainfall, runoff, and soil moisture are necessary to comprehend regional variations in drought (Sheffield & Wood, 2020). One of the most important metrics for tracking meteorological droughts is precipitation (FAO, 2021). Several studies have shown that long-term monthly precipitation data, together with the Standardized Precipitation Index (SPI) (Wambua et al., 2015; Zhang et al., 2012), may be used to forecast when droughts or heavy rains would occur. Droughts may be categorized according to climatic, agricultural, hydrological, or socioeconomic factors, according (Modarres & Sarhadi, 2010). Despite their differences in nomenclature, these droughts are interconnected and may have devastating effects. The absence of typical conditions—whether caused by rain, soil moisture, stream runoff, groundwater, or groundwater recharge—is a hallmark of all droughts. A meteorological drought will be followed by an agricultural drought, a hydrological drought, and lastly a socioeconomic drought; all these kinds of droughts are interrelated (Wang et al., 2022). Drought is one of the most adverse climatic conditions that could occur in Sudan because most Sudanese people depend on rainfall for agriculture; hence, the economy and food security have experienced recurrent episodes of drought, contributing to its ongoing climatic challenges and the most pronounced period of prolonged aridity that transpired between 1980 and 1984, resulting in a significant scarcity of precipitation and subsequent famine events. Moreover, it is worth noting that relatively milder drought occurrences were documented from 1967 to 1973, 1987, 1989, 1991, 1993, and 2000, as reported by Mbogo (2014). Although observed, these particular drought events, although observed, have exhibited limited long-term impacts on the overall environmental conditions. Based on the findings of Ana (2013), there has been a discernible upward trend in temperature and a corresponding decrease in rainfall over the course of recent decades. These climatic changes may potentially be attributed as the primary drivers behind the occurrence of drought conditions in Sudan. Based on the research conducted by Ji et al. (2023), it is suggested that the observed decline in precipitation could potentially be associated with fluctuations in atmospheric moisture. Additionally, our findings indicate that on smaller spatial scales, the movement and convergence of moisture play a crucial role in the observed rainfall patterns in the Sudan-Sahel region. In wet conditions, we observe a distinct presence of westward moisture flux, while in dry conditions, an eastward moisture flux is evident. The primary precipitation period in Sudan occurs from June to September, commonly referred to as the June to September (JJAS) monsoon season. According to Zhang et al. (2012), a notable decline in the overall annual precipitation was observed in the central region of Sudan from 1948 to 2005. This decline can be attributed to the weakening of the African summer monsoon. Drought is a highly challenging climatic phenomenon that can have significant implications for Sudan, as a substantial portion of the Sudanese population relies on rainfall for agricultural activities, which in turn impacts the economy and food security of the region. Drought is an intricate climatic phenomenon that poses challenges in terms of its prediction, encompassing its onset, cessation, and intensity (Wilhite 2016). The primary aim of this study is to elucidate the occurrence of drought as an exceptional climatic phenomenon in Sudan by enhancing comprehension of the temporal and spatial patterns of droughts through the utilization of the Standard Precipitation Index (SPI) and Anomaly.

2. Data and Methodology

2.1. Study Area

Sudan, located in northeast Africa, has specific geographical coordinates. It lies between latitudes 8-N and 23-N, and longitudes 21-E and 38-E (**Figure 1**). With a land area of over 1.80 million square kilometers, Sudan has a population of around 32,419,620 people (Mohamed & Bannari, 2016). Sudan comprises an

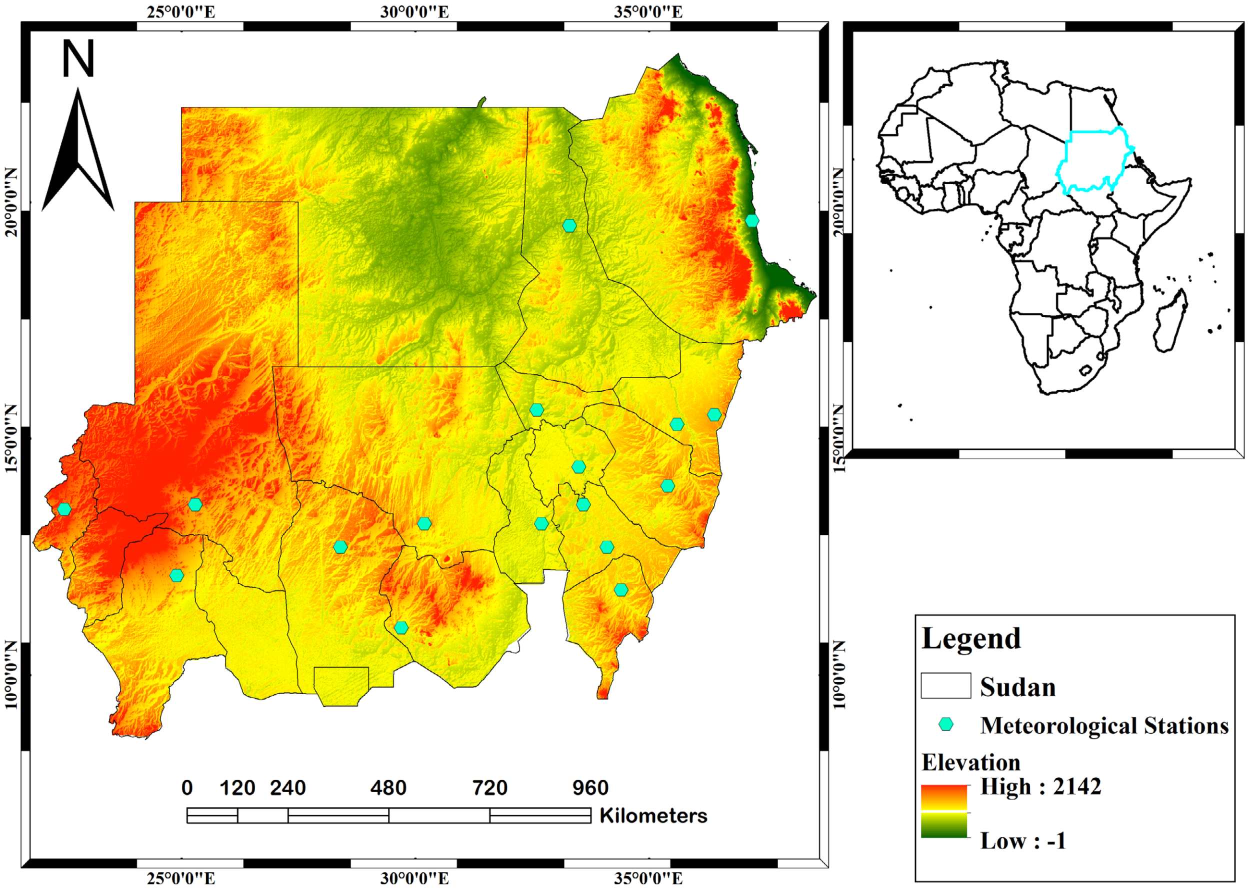

Figure 1. The study area of Sudan map showing distribution of synoptic stations with their elevation.

expansive plain flanked by mountains on three sides. These include the Jebbel Marra to the west, the Nuba mountains in the south, and the Red Sea hills in the southeast. The Sudanese plain encompasses notable areas in the north and south, each exhibiting distinct features—the region of Northern Sudan. The regions of Western Sudan, central clay plains, eastern Sudan, and clay plains in the southern section of the country are geographically significant areas within Sudan, except for a limited region in northeastern Sudan, where intermittent runoff is discharged into the Red Sea or rivers from Ethiopia flow into shallow ponds that undergo evaporation to the west of the Red Sea Hills. The entire country includes the drainage system of the Nile River and its two primary tributaries, the Blue and White Niles. The Nile, often recognized as the longest river globally, spans a distance of 6737 km, originating from its most remote sources in central Africa and ultimately reaching the Mediterranean Sea northwest (Ana, 2013).

2.2. Data

We used Precipitation datasets from the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) for our analysis. The dataset covers the years 2001 to 2015 and has a spatial resolution of (0.05˚ 0.05˚). You can access the data source at https://iridl.ldeo.columbia.edu/SOURCES/.UCSB/.CHIRPS/.v2p0/.daily-improved/.global/.0p05/.prcp. According to Muthoni et al. (2019), CHIRPS-v2 data demonstrate strong temporal consistency and accurately capture rainfall variability compared to gauge observations, indicating its reliability in representing rainfall patterns in Eastern Africa. Additionally, Dinku et al. (2018) show that CHIRPS products perform significantly better and have higher capabilities with minimal or no bias across East Africa. Kimani et al. (2017) and Alriah et al., (2022) also find that CHIRPS accurately estimates rainfall over East Africa during the wet season and captures different rainfall regimes.

2.3. Methodology

1) Anomaly

The anomaly method is a technique used to assess the discrepancies between observed precipitation and the long-term average for a specific period and location. Through this comparative analysis, one can determine the degree to which precipitation has deviated from the expected values. Positive anomalies indicate an excess of precipitation, while negative anomalies suggest a deficiency of precipitation compared to the long-term average (Wilks, 2006). To calculate precipitation anomalies, one can use the following equation:

$$X_{dt} = x_t - \overline{x} \tag{1}$$

$$t = 1, 2, \cdots, n \tag{2}$$

2) Standardized Precipitation Index

The Standardized Precipitation Index (SPI) is a drought index that measures precipitation deficits over various time intervals (Guenang & Kamga, 2014). The SPI is an easy-to-use, adaptable index that is used worldwide to track terms related to drought. SPI values are normalized so that a zero SPI represents the mean precipitation, a negative SPI value indicates less precipitation than the median (drought conditions), and a positive value indicates more precipitation than the median (wetter conditions) (Physics, 2014; Zhang et al., 2012). Drought severity or wet conditions are categorized based on certain thresholds as shown in Table 1. Drought is categorized as follows:

$$\mathrm{SPI} = \frac{X_i - \overline{X}}{\sigma} \tag{3}$$

3. Results and Discussion

3.1. Results

3.1.1. Temporal and Spatial Distribution of Rainfall in Sudan for the Period 2001-2015

Figure 2(a) presents a comprehensive summary of fluctuations in summer precipitation (JJAS) in Sudan from 2001 to 2015. Notably, the highest level of precipitation recorded during this period was 256 mm in 2007, indicating a relatively

Table 1. SPI values for categorizing drought intensity.

Drought Intensity Categorization	The SPI Values
Extreme wet	SPI ≥ 2 +
Severe wet	1.5 < SPI ≤ 2
Moderate wet	1 < SPI < 1.5
Near normal	−1 < SPI ≤ 1
Moderate dry	−1.5 SPI ≤−1
Severe dry	−2 < SPI ≤−1.5
Extreme dry	SPI < −2

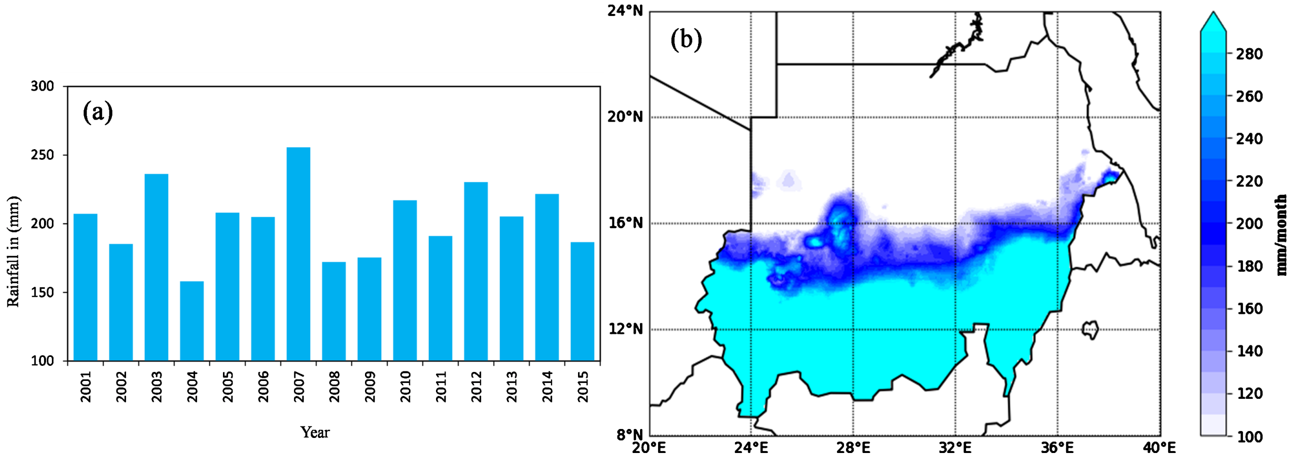

Figure 2. Displays the temporal and spatial distribution of rainfall in Sudan for the period 2001-2015, with a focusing on seasonal rainfall during the June-August (JJAS) period and annual rainfall. The figures illustrate the distribution of rainfall.

wet year. In contrast, 2004 had the lowest recorded precipitation of 158 mm, indicating a relatively dry year. Figure 2(b) illustrates the spatial distribution of the monthly mean average JJAS rainfall for the period 2001-2015, revealing heightened rainfall in the southern regions encompassing Greater Darfur, Greater Kurdufan, and Blue Nile states. In contrast, the northern parts of Sudan experienced lower rainfall, as indicated by gridded data. This finding highlights the contrasting precipitation patterns across the country over the specified years.

3.1.2. The Annual Average Precipitation in Sudan Was Compared to Some Drought Events for the Years 2004, 2008, and 2009

The comparison presented in Figure 3 displays the spatial average of rainfall over an extended period. Figure 3(a) contrasted with dry years that took place in 2004-2008-2009 (Figure 3(b)-(d)). An analysis of the seasonal rainfall in 2004 Figure 3(b) indicated the widespread impact of dry event across the area of the study, with a more severe effect observed in the Northern area, while West, Central, and South Darfur remained relatively genuine. Examining the JJAS precipitation in 2008 Figure 3(c) revealed a region-wide drought with a pronounced impact on southern and northern Darfur. A region-wide drought with a significant effect on southern and northern Darfur was found by analyzing the seasonal rainfall in 2008 Figure 3(c). Moreover, drought-affected regions in central,

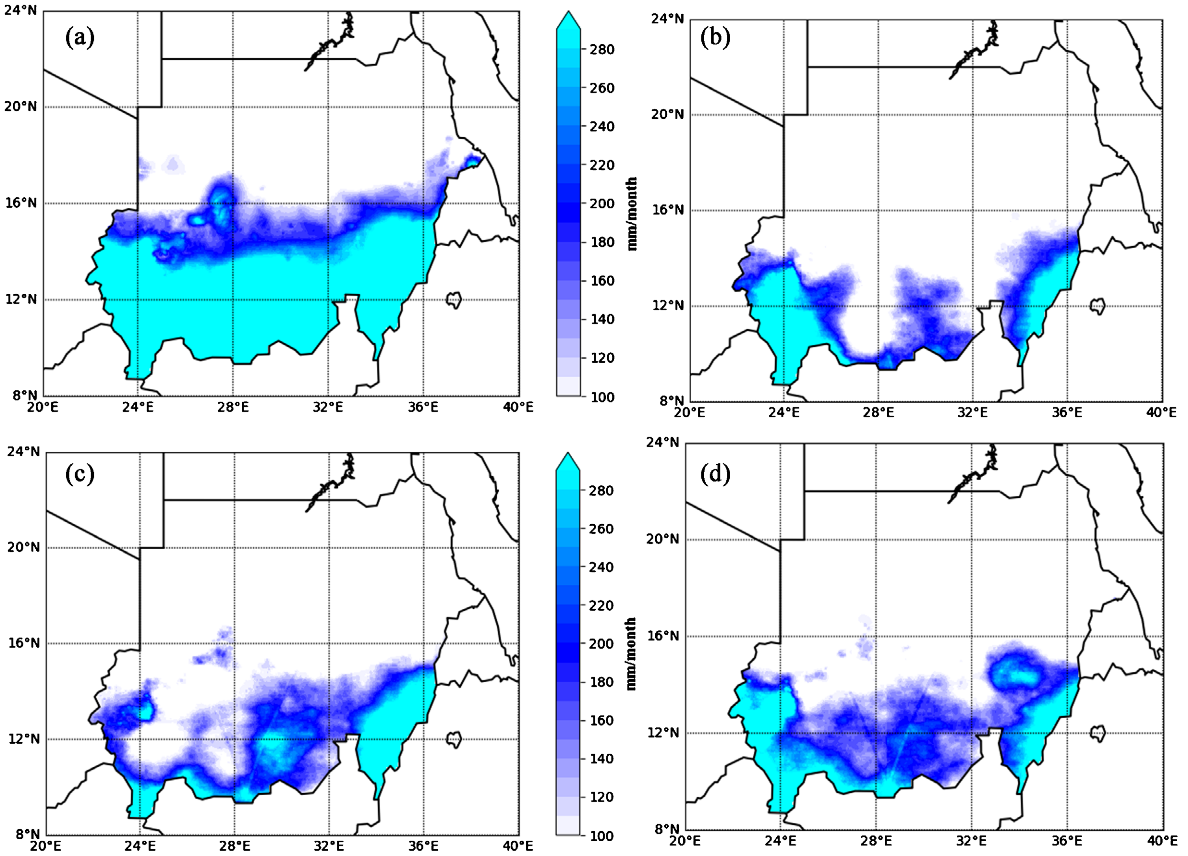

Figure 3. (a) Total Annual Mean of Precipitation for 2001-2015 comparing to three drought events (b)-(d) in Sudan for 2004, 2008 and 2009.

western and southern parts were depicted in Figure 3(d) of the seasonal rainfall in 2009.

3.1.3. The (SPI)

From 2001 to 2015, in Sudan the standardized precipitation index (SPI), as shown in Figure 4, indicates periods of dryness and wetness in the area. The figure shows that significant dry years took place in 2004, 2008, and 2009, as

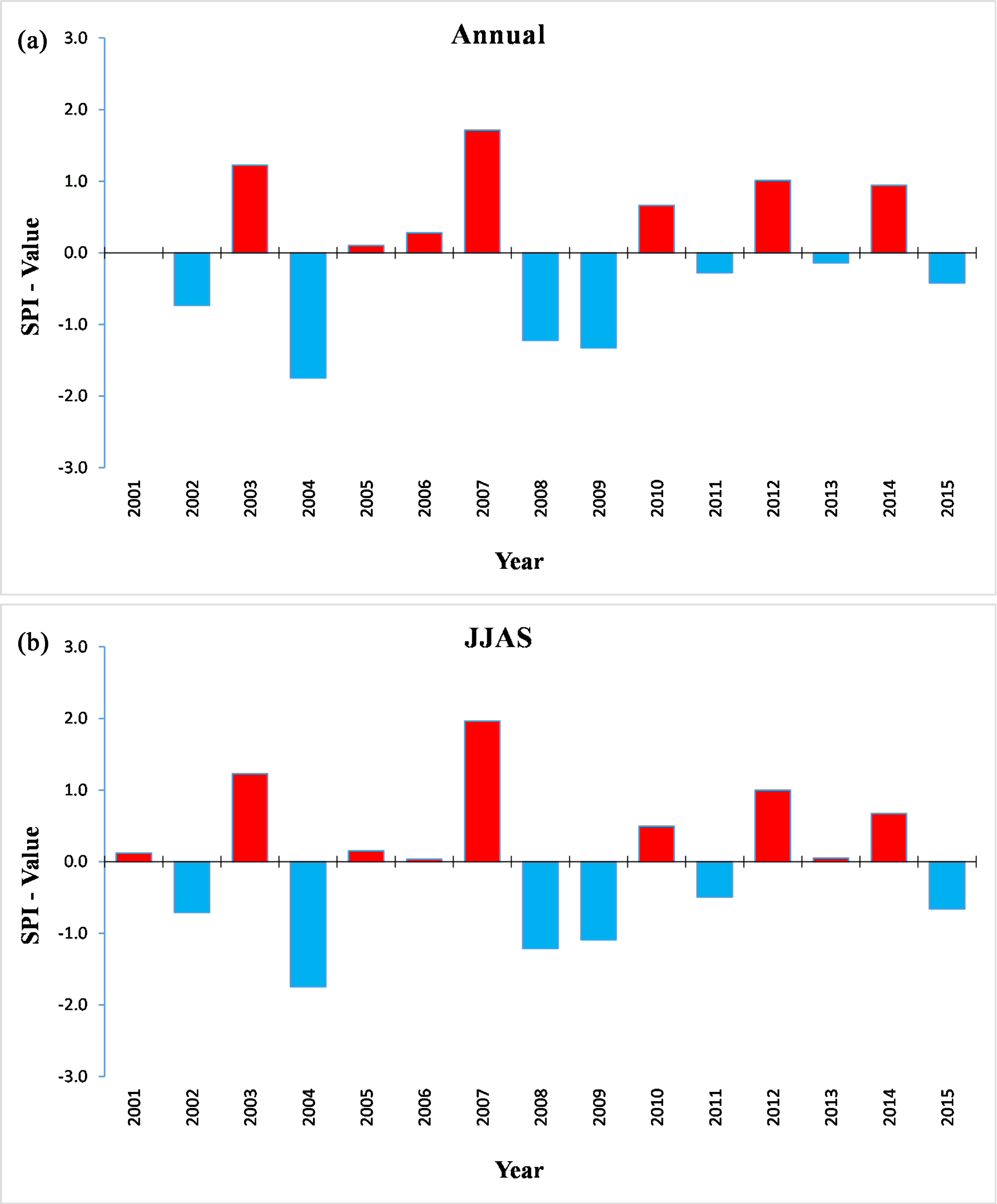

Figure 4. Temporal variation in SPI-1 for ((a), (b)) annual and (JJAS) precipitation over Sudan from 2001 to 2015. calculated based on precipitation from the (CHIRPS). This figure shows the changes in these indices over time.

indicated by annual precipitation (**Figure 4(a)**). Severe dry conditions (SPI ≤ −1.5) characterized 2004. Additionally, the seasonal JJAS precipitation shown in **Figure 4(b)** highlights the major dry events in 2004, 2008, and 2009. It should be noted that 2008 and 2009 experienced moderate drought conditions (SPI ≤ −1), whereas 2004 with (SPI ≤ −1.5) was classified as a severe drought year. These findings underscore the recurring and prolonged droughts that affected Sudan from 2001 to 2015.

3.2. Discussion

The findings of the study (**Figure 2(b)**) are in line with previous research conducted by El Gamri et al. (2021) and Zhang et al. (2012), who also observed variations in rainfall patterns in Sudan. The decrease in the rainfall recycling ratio from south to north indicates a shift in the distribution of precipitation over time in the region. By examining the Standardized Precipitation Index (SPI) during the period from 2001 to 2015 (**Figure 4(a)**), we can observe a pattern of alternating wet and dry periods, with notoriously dry years occurring in 2004, 2008, and 2009. These outcomes support the findings of Elnour et al. (2017), who stated that extended dry spells were prevalent in the western part of the country throughout the study period, particularly between 2007 and 2011. However, it is important to acknowledge the limitations of this study in terms of its generalizability, as it relies on the availability of data.

4. Conclusion

This study highlights the urgent need for proactive drought management and mitigation strategies in Sudan. The study emphasizes that drought is a persistent and recurrent issue in the region, as evidenced by the Anomaly and Standard Precipitation Index (SPI) indicating the frequency of droughts in Sudan. These findings stress the importance of targeted interventions to address the impacts of drought on water scarcity, crop failures, and socio-economic challenges. It is recommended to calculate the SPI for individual stations rather than relying solely on area averages. This approach can provide a more detailed understanding of local drought conditions. In addition, implementing proactive measures such as water conservation, cultivating drought-resistant crop varieties, and establishing early warning systems can help communities in Sudan better prepare for and mitigate the effects of droughts.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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