American Journal of Climate Change, 2022, 11, 230-249
https://www.scirp.org/journal/ajcc
ISSN Online: 2167-9509
ISSN Print: 2167-9495

Drought Monitoring and Assessment of Climate Parameters Variability in Koutiala and San Districts, Mali

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How to cite this paper: Doukoro, D., Abbey, G. A. & Kalifa, T. (2022). Drought Monitoring and Assessment of Climate Parameters Variability in Koutiala and San Districts, Mali. *American Journal of Climate Change*, *11*, 230-249.
https://doi.org/10.4236/ajcc.2022.113011

Received: May 18, 2022
Accepted: September 26, 2022
Published: September 29, 2022

Abstract

In Mali, the annual temperature, rainfall, and evapotranspiration are high variables. Their distributions are unevenly spread from north to south. Climate change strengthens to increase air temperature and evapotranspiration. It also increases the intense rainstorms and the risk of drought associated heat waves. Drought is considered a natural disaster among all hydrologic extremes. It causes severe damage to the environment, agriculture, and livelihoods relying on water resources. The present study evaluated the variation of drought indices from 1989 to 2019 in Koutiala and San districts, respectively. Therefore, the Standardized Precipitation Evapotranspiration Index (SPEI) was applied. Hence, the Mann-Kendall (MK) test was used and for 12-month time-scales. Trend analysis of monthly precipitation, temperature, and evapotranspiration has been done by using the MK test. Based on the analysis result, the climate of the Koutiala and San districts has been classified as moderate to severe drought category. However, this result clearly shows SPEI pattern changes in both districts. The monthly precipitation showed a significant decreasing trend in Koutiala and San districts. In comparison, the monthly temperature and evapotranspiration displayed an increasing trend in both districts.

Keywords

Drought, Climate Parameters, SPEI, Trend, Mann-Kendall, Koutiala, San, Mali

1. Background

Climate change now affects both natural and anthropic ecosystems, and is of significant concern to the scientific community and policymakers (IPCC, 2018; Ouhamdouch et al., 2020; Bahir et al., 2020). According to the latest estimations from the Intergovernmental Panel on Climate Change (IPCC, 2018), human activities have caused global warming of 1˚C above pre-industrial levels, with a range of 0.8˚C - 1.2˚C. This warming could reach 1.5˚C between 2030 and 2052 if it continues to increase at the current rate (IPCC, 2018). This climate change could impact a large panel of sectors and activities by raising pressure on water resources, reducing agricultural productivity, and more significantly, developing vector-borne and water-borne diseases (IPCC, 2014). In addition, a continuous increase in temperatures could intensify the hydrological cycle and lead to the more frequent occurrence of extreme weather events (Chaouche et al., 2010; Tao et al., 2015; Rahman et al., 2018; Wilcox et al., 2018; Ouhamdouch et al., 2020). Climate change is expected to increase the frequency and intensity of droughts in many parts of the world, including Africa. Drought causes widespread suffering and the loss of rural communities.

According to a publication of CEDEAO-Club Sahel/OCDE/CILSS on Climate and Climate Change (2008), in the West African Sahel, an increasing trend was observed in both maximum and minimum temperatures for all the three ecological zones (Sudanian, Sahelian, and Sahel-Saharan) with minimum temperature increasing at a faster rate. The persistence of dry years from 1970 to 1993 (Toure, 2017; L'Hote et al., 2002) was found in the southward movement of isohyets by about 200 km (Diouf, 2000). Toure (2017) showed that in the region after 1993, another type of variability characterized by an alternation between very dry and wet years has begun. Furthermore, the same author indicates that while there is a tendency of persisting drought in the Western Sahel, the east is experiencing a gradual return to wetter conditions. However, recent studies in Africa, when analysing daily climate in terms of trends and extreme indices, revealed some significant increases and decreases in annual precipitation; increases in longest wet spells, increases in high daily precipitation amounts, and average rainfall intensity (New et al., 2006; Alexander et al., 2006; Donat et al., 2014).

Agriculture is the backbone of Africa's economy and contributes about 30% to the gross domestic product (GDP) annually (Paschal et al., 2019). Additionally, the sector accounts for 65% of Africa's total exports and provides more than 80% of informal rural employment, making agricultural success a key to food security and reduction of poverty (Asafu-Adjaye, 2014). In Mali, the economy heavily depends on the primary sector: agriculture, livestock, fishing, and forestry occupy 68.0% of the working population. This sector is dependent on exogenous factors, mainly climatic factors such as recurrent droughts, floods and producers' precarious technical, and economic capacities (ENSAN, 2016).

Being landlocked, Mali is estimated to be among the most vulnerable countries to climate stress due to its socioeconomic status, location, and climate-sensitive economy. Agro-pastoralist provides livelihoods for 80 percent of Malians and is highly sensitive to the droughts and rainfall variability typical of the Sahel region (USAID, 2018). According to USAID (2018), the recurring extreme events such as severe drought in the 1970s and 1980s, five major droughts from 1987 to 2007, and catastrophic floods prevent households from recovering and moving out of poverty. Nowadays, climate change is a reality that presents a significant threat to agricultural production systems in Mali (Bouba et al., 2018). According to the World Bank (2019), in Mali, 400,000 people live in areas expected to experience water scarcity each year, predominantly in the southern regions. According to Bouba et al. (2018), the increase in inter and intra-seasonal variability of precipitation and temperature variability as well as, the extreme weather events (drought, flooding, high temperatures, and high winds) as a result of climate change, will seriously affect crops, livestock, food security, and others livelihoods for the predominantly poor populations in Mali. In Mali, the rainfall declined rapidly between 1950 and the mid-1980s, partially recovered in the 1990s, and then declined slightly in the 2000s (Fact Sheet, 2012). In most areas in Mali, agricultural production systems are faced with drought problems that manifest themselves in various forms. The most recurrent and critical dry spells occur at the beginning and end of the season (Bouba et al., 2018). Climate change is expected to increase vulnerability in all Agro-ecological zones of Mali through rising temperature and more erratic rainfall, which will have drastic consequences on food security and economic growth (Butt & McCarl., 2006; Dell et al., 2012). Climate change projections from the Hadley Centre Coupled Climate Model (HADCM) and Canadian Global Couple Climate (CGCM), suggest that by the year 2030, Malian average temperature may increase by 1˚C - 2.75˚C and 2˚C - 4˚C before 2060 (Butt et al., 2005; Butt & McCarl., 2006; Konate, 2010). However, the impact of these changes on rainfall characteristics is 20% - 60% yield losses for agricultural productions by 2025 (Butt et al., 2005). Moreover, the biophysical basis is relatively clear-cut: rainfall characteristics affect water balance, specifically water availability and evapotranspiration, and plant physiology directly (Dell et al., 2012).

Drought is classified into three categories: Meteorological, hydrological, and agricultural drought. Meteorological drought is a lack of precipitation over a region for a specific timespan lasting sufficiently to cause a water deficit and agricultural threat. Short-term drought (1 and 3 months) drought considered a meteorological drought takes the shorter time of prevailing water deficiency in the region. Average term drought (6 months) is considered an agricultural drought. Accumulation water deficiency during crop growing season generally takes three months, whereas most crops take six months to develop, harming the crop yield fully. Long-term drought indices (9, 12, and 24 months) are considered hydrological drought. Hydrologic drought results from water deficiency in water storage in rivers, streams, and other reservoirs. Identifying drought is crucial to mitigate its effect, and it helps in taking measures while planning for development.

Drought indices are used to identify and characterize drought intensity, duration, and severity. Standardized Precipitation Evapotranspiration Index (SPEI) (McKee et al., 1993) is a standard indicator of drought. It required the monthly rainfall and evapotranspiration as input climate variables to calculate the SPEI. However, deficit precipitation and increased temperature increase the severity of drought in the arid and semi-arid regions (Vicente-Serrano et al., 2010). The main objective is to identify drought events, their variability, and severity using drought indices SPEI. In addition, to evaluate the trend analysis of climatic variables, i.e., monthly precipitation, temperature, evapotranspiration mean in Koutiala and San districts in Mali.

2. Materials and Methods

2.1. Study Area

This study is implemented in two districts of Mali, namely Koutiala (Sikasso region) and San (Segou region) (**Figure 1**). This area (Southern Mali) occupies 13.5% (approximately 160.825 km^2) of the Malian territory and represents 50% of the cultivable lands of the country and holds 40% of the Malian population (Mali minister of environment, 2017).

Koutiala District is in the heart of the old cotton basin and occupies the western part of the Sikasso region. It is bounded on the north by San District (cercle), northwest by Bla, and southwest by the Dioïla District, to the south by the district of Sikasso and the Republic of Burkina Faso, and on the east by the District of Yorosso. The geographical location of the district is 12˚23'N 5˚28'W.

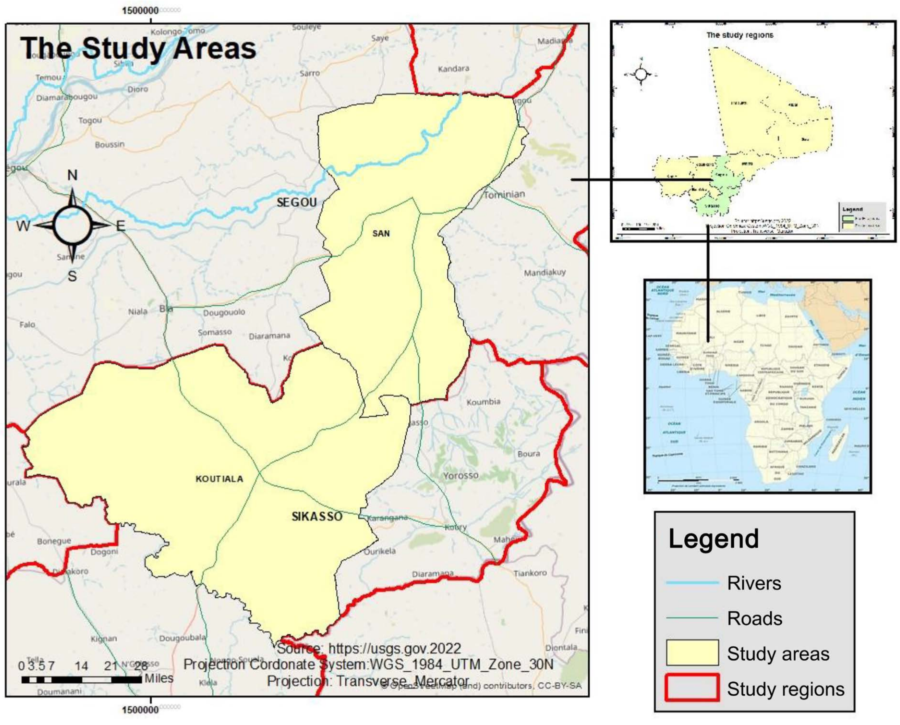


Figure 1. Study area (Koutiala and San districts). **Source:** Personal work.

The Koutiala district covers an area of 8740 km^2 with a population of 797,927 inhabitants. The climate is tropical sub-Saharan and characterized by two seasons in a year: a dry season from November to April and a rainy season from May to October. The rainfall in Koutiala ranges from 750 to 1000 mm per year. The rainy season lasts from June to October, with rainfall peaking in August. The dry season comprises a relatively cold period from November to February and a hot period lasting from March to May. The average maximum temperature is 34˚C during the rainy season and 40˚C during the hot, dry period (Bandiougou et al., 2017). The district has neither a river nor large lakes; yet we can distinguish surface water and wells, generally fed by rainwater (RGPH, 2009; Mali-Meteo, 2019; Institut National de la Statistiques, République du Mali, 2009).

The district of San is part of the semi-arid zone and is characterised by a Sudan-Sahelian climate. It has a surface of 7262 km^2 with a population of 335,000 inhabitants. Its geographical location is 13˚10'44.2"N 5˚0'58.2"W. It has a tropical dry wither with an average maximum temperature of 44˚C, and the lowest temperatures are 13˚C. This district is hot on average all year round, with the warm months being March and May. November to February is the coolest month. The rain season occurs with the peak in June, July, August and September. The annual average rainfall is around 500 mm per year (RGPH 2009; Mali-Meteo 2019; Institut National de la Statistiques, République du Mali, 2009).

The topography of the Koutiala and San districts involves plateaus, sloping lands, and lowlands. The soil textures are predominantly clay, sandy loam, and sandy soils. Sandy soils have low organic matter and low infiltration capacity. Due to their poor level of fertility and poor water retention capacity, sandy soils are mainly favourable to millet production, which tolerates low fertility and water scarcity. Cotton, sorghum, and maize are grown in loam, sandy soils, and clay because of the higher quality of these soils (Coulibaly et al., 2011).

Koutiala and San are one of the largest cereal production zones in the country. Millet, sorghum, and maize are the main staple foods produced in those zones. Rice is also grown in the zones. These crops serve for home consumption as well as being marketed. Both cereal and cotton are produced under rain-fed conditions. Koutiala is the main cotton-growing area, producing 200,000 tons during the CMDT season of 2008/2009. Cereals are grown in rotation with cotton, which allows them to benefit from the residual effect of fertilizers used in cotton.

Agriculture is the main activity of the population. The main crops are millet, sorghum, maize, and rice, which form the basis of the diet. Market gardening and fruit growing also provide income. Livestock breeding, fishing, and handicrafts are the occupations of the population that are part of the local economy. Poultry farming, beekeeping and fish farming are developing more slowly.

The following **Figure 1** is about the presentation of the study areas where this study was conducted

2.2. Data Used

To calculate Standardized Precipitation Evapotranspiration Index (SPEI), and trends analysis for this study, the monthly meteorological data from 1989 to 2019 were collected from two main meteorological stations (Koutiala and San) in the Republic of Mali. The data includes: mean annual temperature (maximum and minimum), mean annual precipitation, and mean annual evapotranspiration.

2.3. Method

2.3.1. Standardized Precipitation Evapotranspiration Index (SPEI) Analyses

The SPEI index is a standardised monthly climatic balance computed as the difference between the cumulative precipitation and the potential evapotranspiration.

SPEI, a modified drought index that includes the effect of global warming on drought severity, was first proposed by Vicente-Serrano et al. (2010). SPEI uses "water balance" (D) as an input variable, is aggregated at different timescales (1, 3, 6,9,12 and 24 months), and these resulting values fit the probability distribution function (e.g. log-logistic) then normalized the water balance to obtain the SPEI. The difference (D) between precipitation (P) and PET for the month is given in the equation below.

$$D = P - PET \quad (1)$$

where D is the difference

where P is the precipitation

where PET is the Potential Evapotranspiration

The calculated D values are accumulated at different time scales

$$D_n^k = \sum_{i=0}^{k-1} P_{n-1} - \left(PET\right)_{n-1} \quad (2)$$

where k is the timescale (months) of accumulation and n is the calculation month.

All negative SPEI values indicate the occurrence of drought, while all positive values stand for wet periods (McKee et al., 1993; Komuscu, 1999). The choice of the timescale depends on the interest of the research. This study used the 12-month timescale to compute SPEI values from 1989 to 2019.

2.3.2. Temporal Trend Analysis

For the analysis of temporal trends in maximum, minimum temperature, precipitation, and evapotranspiration, the Mann-Kendall test (Mann, 1945; Kendall, 1975a; Caloiero et al., 2011), a nonparametric method for trend analysis, were used. It should be noted that the Mann-Kendall statistics test is non-dimensional. It does not offer any quantification of the trend's scale in the units of the time series under study. Still, it is instead a measure of the correlation of a variable with time and, as such, offers information as to the direction and a measure of the significance of observed trends. The Mann-Kendall statistic test S is given as follows:

$$S = \sum_{j=1}^{n-1} \sum_{i=j+1}^{n} Sign\left(x_i - x_j\right) \quad (3)$$

where x_i and x_j are the data value at time i and j
where n is the length of the dataset
where $sign\left(x_i - x_j\right)$ is the sign function which can be computed as:

$$Sign\left(x_i - x_j\right) = \begin{cases} 1 & \text{if } \left(x_i - x_j\right) > 0 \\ 0 & \text{if } \left(x_i - x_j\right) = 0 \\ -1 & \text{if } \left(x_i - x_j\right) < 0 \end{cases} \quad (4)$$

For $n > 10$, the test statistic Z approximately follows a standard normal distribution:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{Var\left(S\right)}} & \text{if } S > 0 \\ 0 & \text{if } S = 0 \\ \dfrac{S+1}{\sqrt{Var\left(S\right)}} & \text{if } S < 0 \end{cases} \quad (5)$$

In which $Var(S)$ is the variance of statistic S.

A positive value of Z indicates an increasing trend, and a negative value indicates a decreasing trend. The null hypothesis, Ho, that there is no trend in the records is either accepted or rejected depending on whether the computed Z statistics are less than or more than the critical value of Z statistics obtained from the normal distribution table at the 5% significance level (Some'e et al., 2013). If $/Z/ > Z(1 - \alpha/2)$, the null hypothesis of no autocorrelation and trend in the dataset is rejected, in which $Z(1 - \alpha/2)$ is corresponding to the normal distribution, with α being the significance level.

If the data has a trend, the magnitude of trend can be denoted by trend slope β (Sen, 1968), (Theil et al., 1950):

$$\beta = Median\left[\frac{x_i - x_j}{i - j}\right], \forall j < i \quad (6)$$

where x_i and x_j are data values at time t_i and t_j ($i > j$), respectively.

3. Results and Discussion

3.1. Standardized Precipitation Evapotranspiration Index (SPEI) Analysis

Figure 2 shows a continuous evolution of SPEI at different levels in the Koutiala district. Therefore, during the period from 1989 to 2019, there was an exceptional wet condition that occurred in 1994 (+2.53), and extreme wet conditions were observed in 1996 (+1.62) and 2010 (+1.62). While in 2013 (−1.52), 2017 (−1.63), 2002 (−1.80), and 2001 (−1.99) an exceptional dry condition was observed (**Table 1**).

Figure 3 revealed that in the San district, there was an exceptional wet condition that occurred in 1994 (+2.26). Moreover, in 2011 (+1.77) an extreme wet condition was observed. In 1996 (+1.60), and 1991 (+1.55) the wet condition was considerably increased in this district. While, in 2001 (−1.74) and 2010 (−2.19), an extreme condition of the drought occurred. In 1990 (−0.99), 1995 (−1.01) and 2004 (−1.37) a moderate drought condition was measured (Table 1).

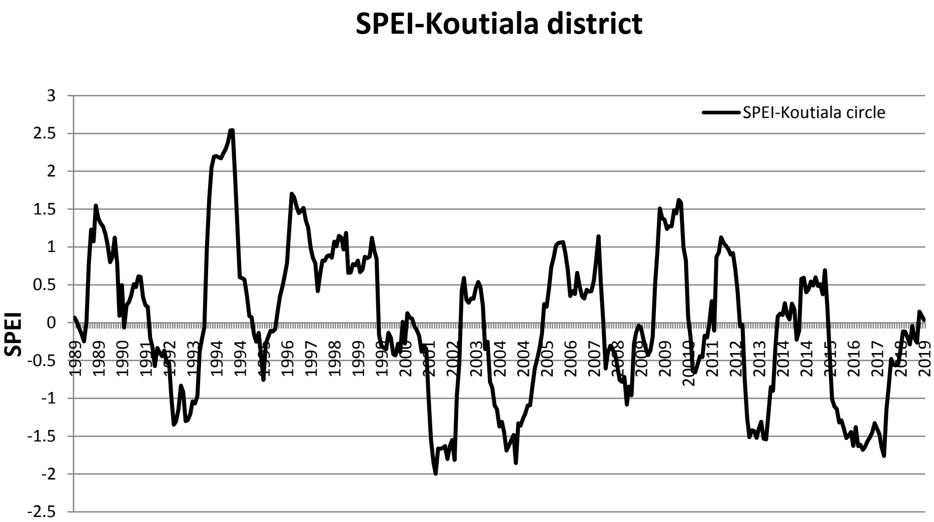


Figure 2. Standardized Precipitation Evapotranspiration Index (SPEI) in Koutiala district. **Source:** Personal work.

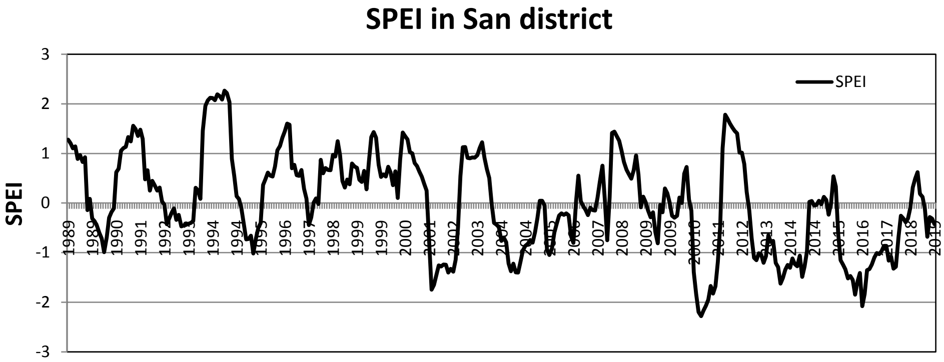


Figure 3. Standardized Precipitation Evapotranspiration Index (SPEI) in San district. **Source:** Personal work.

Table 1. Establishment of drought level according to SPEI index values.

Color	Categories	Index values	Color	Categories	Index values
🟪	Exceptionally drought	≤−2.326		Highly wet	+0.524 to +0.935
🟥	Extremely drought	−1.645 to −2.326		Moderately wet	+0.935 to +1.282
🟧	Severely drought	−1.282 to −1.645		Considerably wet	+1.282 to +1.645
🟧	Moderately drought	−0.935 to −1.282		Extreme wet	+1.645 to +2.326
🟨	Minor drought	−0.524 to −0.935		Exceptionally wet	≥2.326
🟩	Near normal	+0.524 to −0.524			

Source: McKee et al. (1993). Each colour refers to the corresponding category of moisture conditions.

In both districts, we observed an extended frequency and duration of drought during the last two decades (from 2001 to 2019). This situation shows the probability of drought occurrences in those districts. However, this result clearly shows SPEI pattern changes in both districts. Thus, the drought is a major cause of agricultural, economic, food security, and environmental damage in those areas. Therefore, in both districts there is a long period with a shortage of precipitation. However, it is difficult to determine the onset, extent, and end of precipitation in those areas. Droughts are recurrent hazards in Mali, as in the wider Sahel region. They have contributed to severe food crises in 1972 - 1974, 1983 - 1985, 2002 - 2003, 2011 - 2012, and 2015 - 2018, partly due to the 2015/2016 El Niño induced drought (World Bank, 2019). Livestock's are an important component of the agricultural economy of Mali, and they are adversely affected during droughts. According to Williams et al. (2011), the role of warming-induced drought stress is evident in recent studies that have analysed drought impacts on net primary production and tree mortality. The empirical studies have demonstrated that higher temperatures increase drought stress and enhance forest mortality under precipitation shortages (Adams et al., 2009). Warming processes are also probably the triggering factors of the decline in world agricultural production observed in the last years (Lobell et al., 2011). Therefore, to illustrate how warming processes reinforce drought stress and related ecological impacts worldwide, Breshears (2005) enunciated the term global-change-type drought to refer to drought under global warming conditions.

The Extended frequency of dry conditions in both districts confirms that there is a probability of drought in this study area in every season due to the variability of precipitation in those areas. At the same time, wet spells occur in those areas sometimes during the season due to climate variability. This result is consistent with this finding from Traore et al. (2015); nearly all farmers claimed that dry spells during the rainy season became longer in Koutiala district. These perceptions correspond with weather records at N'Tarla, showing that the number of dry days increased significantly between 1965 and 2005 ($p < 0.05$). According to Traore (2014), there is an increase in temperature during the dry season as well as rainy season. Sultan & Janicot (2003) indicate that the first rains are not always followed by the full start of the monsoon. Dry spells can occur afterwards, i.e. during the early stages of crop growth, so that seeds may not germinate properly or germinated plants may die off. However, if sowing is delayed, the land may be too wet to till.

Frequent dry spells with high evapotranspiration demand may lead to a decrease in the yield of up to 40% because of insufficient water supply during the grain filling stage (Barron et al., 2003). Consequently, the significant increase in the number of dry days during the rainy season and its impact on yield makes it one of the most important characteristics of climate change in southern Mali. In both districts (Koutiala and San), the farmers identified the late start and early end of the rainy season, the decrease in annual precipitation, the increase in temperature, and the increased occurrence of dry spells as a crucial indicator of climate change (Diarra, 2021). Significant relationships between observations and farmer perceptions of climate change were found in several other countries (Apataet al., 2009; Deresa et al., 2010). According to Ekpoh & Nsa (2011), Some of the consequences of drought in northern Nigeria include ecosystems modification, dislocation of social and economic activities, crop failure, livestock death, declining water table including shortage of water for domestic, industrial, accumulation of water deficiency during crop growing, water deficiency of water storage in the river, streams and other reservoirs and increased temperature and sedimentation of surface water as a result of increased evaporation and transportation of loose soil particles.

3.2. Trends Analysis of Climate Parameters with Mann-Kendall Test

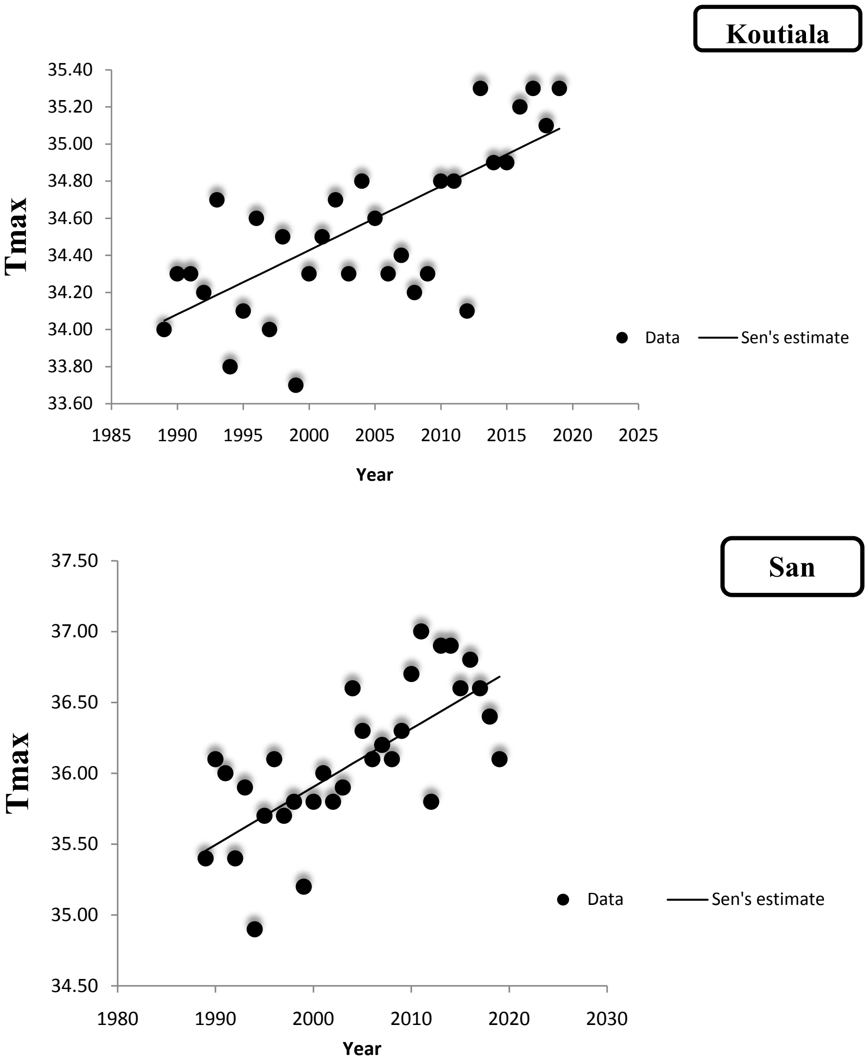
Monotonic increasing or decreasing trends in annual maximum, minimum temperature, evapotranspiration, and precipitation were tested from 1989 to 2019 in the study area using Mann-Kendall test (Z-statistic) and Sen's slope estimator (Q). Annual trends of climate parameters obtained by Mann-Kendall and Sen's slope estimator are given in **Table 2**.

A positive value of Z indicates that there is an increasing trend, and a negative value indicates a decreasing trend (Kendall, 1975b). Therefore, **Figure 4** shows an extremely significant increase trend in maximum temperature (Z=3.97, Z=4.01) recorded in Koutiala and San districts, respectively. At the same time, there was a highly significant increase trend in minimum temperature in the Koutiala district (Z=2.89) and an extremely significant increase trend in minimum temperature in the San district (Z=3.82). However, the temperature recorded is above the mean (34˚C and 36˚C) in both districts. Similar results were obtained by Collins et al. (2011), in which an increased trend in air temperature has been reported in different parts of the world, including the tropical region in Africa. Collins et al. (2011) reported a significant increasing trend in temperature for all of Africa, as well as the Northern Hemisphere Africa, Southern Hemisphere Africa, tropical Africa, and subtropical Africa. Since 1975, temperatures have increased by more than 0.8˚ Celsius (˚C) across most of Mali, with typical warming rates more significant than 0.2˚C per decade (Fact Sheet, 2012). This transition to an even warmer climate could reduce crop harvests and pasture availability, amplifying the impact of droughts. According to CEDEAO-Club Sahel/OCDE/CILSS (2008) on Climate and Climate Change, in the West African Sahel, an increasing trend was observed in both maximum and minimum temperatures for all the three ecological zones (Sudanian, Sahelian, and Sahel-Saharan) with minimum temperature increasing at a faster rate. This temperature increasing can result in reduced fodder yield, an increasing in evapotranspiration, a possibility of migration and conflict between livestock and crop farmers, as well as in the economical, physical and psychological costs (Thornton et al., 2009; Sirohi & Michaelowa, 2007). Further, this temperature increase also impacts human health (McMichael et al., 2012).

Table 2. Trend analysis values of annual climatic variables in Koutiala and San districts.

Time series	First year	Last year	n	Koutiala			San		
				Mann-Kendall test		Sen's slope estimate	Mann-Kendall test		Sen's slope estimate
				Test Z	Sig.	Q	Test Z	Sig.	Q
Temperature maximum	1989	2019	31	3.97	***	0.034	4.01	***	0.041
Temperature minimum	1989	2019	31	2.89	**	0.029	3.82	***	0.033
Precipitation	1989	2019	31	0.95	n.s	3.118	0.99	n.s	3.546
Evapotranspiration	1989	2019	31	3.47	***	16.600	2.65	**	11.380

Source: Personal work. * statistically significant trend at *p*-value = 0.05 with 90% confidence level; ** highly statistically significant trend at *p*-value = 0.01 with 95% confidence level; *** extremely statistically significant trend at *p*-value = 0.001 with 99% confidence level. n.s: Non-significant.



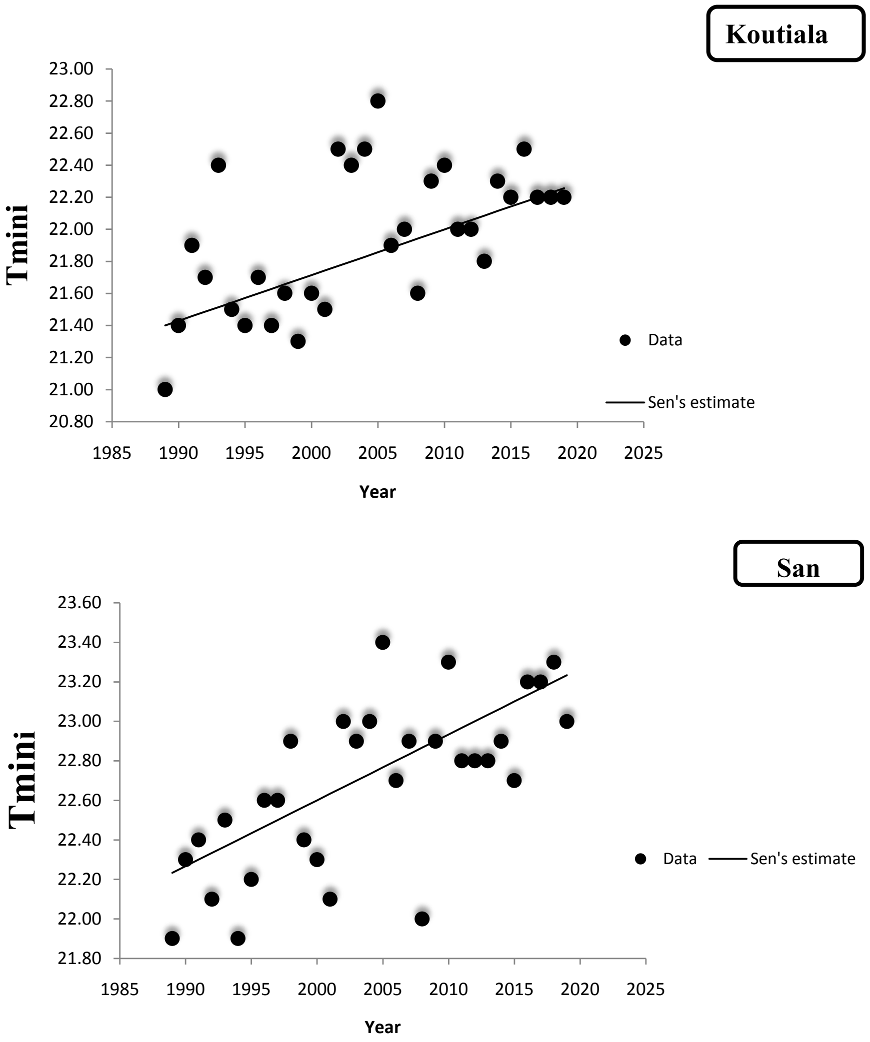


Figure 4. Trend of maximum and minimum temperature from 1989 to 2019 in Koutiala and San districts. **Source:** Personal work.

Figure 5 indicates that there was no significant trend in precipitation (Z=0.95 and Z = 0.99) in both districts. This result is consistent with the third national communication of UNFCCC in Mali (UNFCCC, 2017). It indicates that the trends in climatic parameters clearly showed a decrease in rainfall and an apparent increase in mean annual temperature. It is reported in the report on Mali's Expected Determined Contribution presented at the COP21 in Paris that situation is more difficult as climate scenarios for the year 2100 predict an average temperature increase of 3˚C and a decrease in rainfall of 22% over the whole country. Rainfall represents a meteorological element that best defines the climate of the tropics in general and Mali in particular. Therefore, the decreases in rainfall impact human activities by relying on rain-fed agriculture. The crop cycles follow the rhythm of rainfall. Precipitation is the main source of water during refilling and layers. If any precipitation ever were to change, the consequence will be multiple for human life. Elsewhere, increased frequencies of extreme rainfall events such as prolonged dry or wet spells mean weaker productive systems. This decrease in

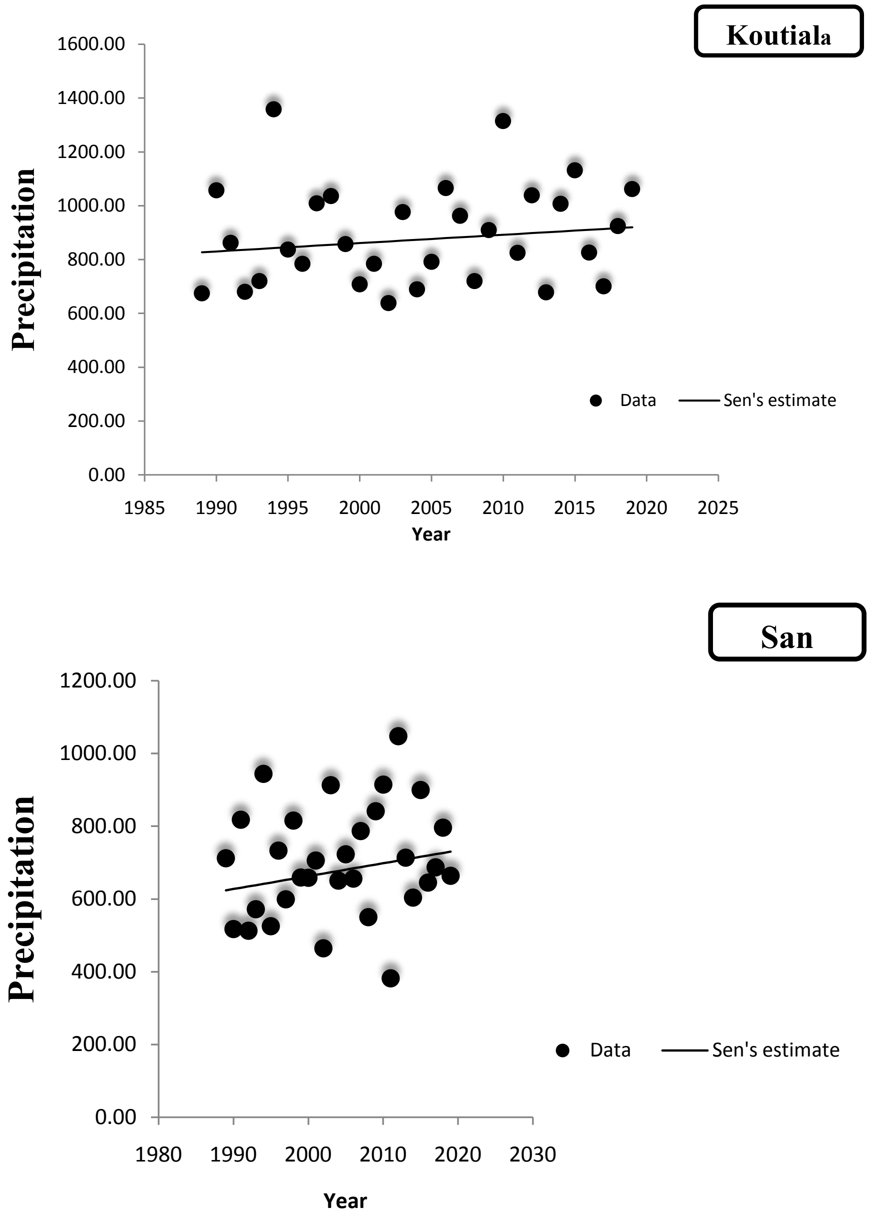


Figure 5. Trend of Precipitation from 1989 to 2019 in Koutiala and San districts. **Source:** Personal work.

annual total rainfall is confirmed in most of Africa (Frappart et al., 2009; Ozer et al., 2009; Hountondji et al., 2011). A similar finding was observed in the overall reduction in rainfall in the studies over the Sahel (Biasutti, 2013; Mohamed, 2011; Ackerley et al., 2011; Lebel & Ali, 2009; Nicholson et al., 2000). It was also found in the study done by (New et al., 2006; Donat et al., 2014) non-significant but in total rainfall positive trends from heavy events for the West Africa and Southern Africa region.

Figure 6 revealed that an extreme significant increasing trend of evapotranspiration ($Z = 3.47$) was recorded in Koutiala district. At the same time, this figure showed a significant increasing trend of evapotranspiration in San district.

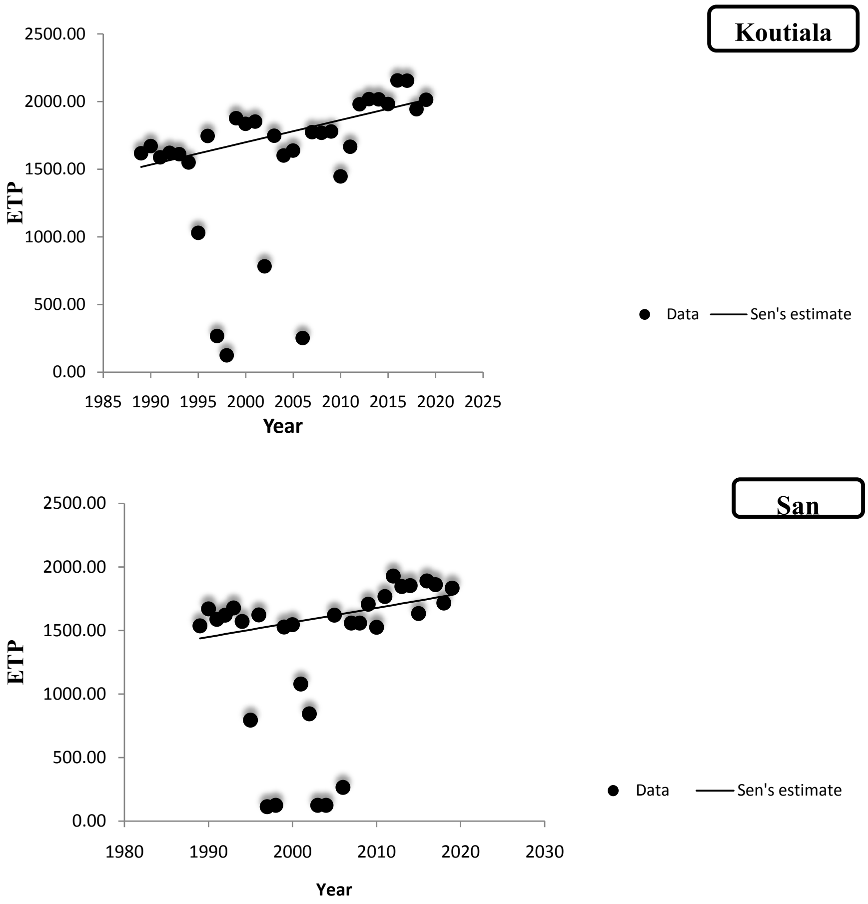


Figure 6. Trend of ETP from 1989 to 2019 in Koutiala and San districts. **Source:** Personal work.

Therefore, this result shows the increase in maximum and minimum in both districts (**Figure 6**). This confirms the studies by Abiye et al. (2019) and Diaye et al. (2020) according to which the temperature (maximum and minimum) is the main factor of variation of evapotranspiration during the periods 1906 - 2015 and 1984 - 2017 in West Africa. According to Komlan et al. (2017) there was an increasing trend of annual evapotranspiration at the rate of 1.4, 1.2, 4.4 and 2.6 mm/year in Senegal. Osbahr et al. (2011) showed that temperature increases led to increase evapotranspiration rates by linking to the faster depletion of soil water. Researchers found the high levels of soil water depletion resulted from high rates of evapotranspiration, usually leading to crop wilting and causing crop failure, which the farmer may be attributed to a decline in rainfall (Halimatou & Kalifa, 2016).

Table 2 gives the summary of the Mann-Kendall test (Z) and Sen's slope estimator (Q) values of climate parameters over the period 1989-2019

4. Conclusion

The standardized precipitation evapotranspiration index (SPEI) has analysed the wet and dry conditions in the study area for the period 1989 - 2019. However, the results confirmed climate variability and change in the study area. Moreover, the frequency of dry spells is high in both districts. Therefore, the drought occurrence is one of the observed disasters affecting the population's livelihoods in the study area. Hence, the floods occur in those areas because of the effects of climate variability and change around the country.

The trend analysis of climatic data (temperature, precipitation and evapotranspiration) for better management in agricultural activities is critical. Therefore, the results showed a positive trend (from 1989 to 2019) for all climatic parameters analysed (maximum and minimum temperature, precipitation, and evapotranspiration) in the study area. However, this trend is significant for maximum and minimum temperature, and evapotranspiration. But the trend is not significant for precipitation in both districts. Moreover, increases in temperature and dry periods are of great concern. It implies an increase in evapotranspiration which affects crop yields. According to much scientific research, the temperature is expected to increase and precipitation is expected to decrease in the future.

The predicted increases in maximum and minimum temperatures for Mali, coupled with reduced or erratic rainfall, are likely to make natural hazards more frequent and severe. Without improved planning and management, the incidence and impacts of these disasters could increase (World Bank Group, 2021).

The information provided by this study can be used to support local level decision-makers in monitoring floods and droughts. Therefore, this study area's agricultural planning and government policies should be based on recent rainfall, temperature, and evapotranspiration trends. This study should be extended to other drought and flood-prone areas all over the country. The impact of climate variability on crop yield should also be investigated.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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