*International Journal of Environment, Agriculture and Biotechnology*
*Vol-8, Issue-6; Nov-Dec, 2023*
*Peer-Reviewed International Journal*
*Journal Home Page Available: https://ijeab.com/*
*Journal DOI: 10.22161/ijeab*

# Statistical analysis of recent rainfall variability and trend using a merged gauge and satellite time series data for the cotton zone of Mali

Souleymane Sidi Traore

Department of Geography, Faculty of History and the Geography, University of Social Sciences and Management of Bamako, Campus of Badalabougou, Bamako, Mali
Joint GIS and Remote Sensing Unit, LaboSEP, Institute of Rural Economy, CRRA-Sotuba, Bamako, Mali.
Corresponding Author: sstraore@yahoo.fr

Received: 03 Oct 2023; Received in revised form: 04 Nov 2023; Accepted: 11 Nov 2023; Available online: 29 Nov 2023


***Abstract*— *The variability of rainfall patterns has a significant impact on people's livelihoods especially in areas where rain-fed agriculture predominates. The temporal variability and trend of rainfall was analysed using a newly rainfall time series created from the fusion with ground measurement and satellite data for ten met stations for the period 1983-2021. Mann Kendall's (MK) non-parametric test was used to verify the rainfall trend, the variability was analysed using the Coefficient of Variation (CoV), the annual distribution of precipitation was checked using the precipitation concentration index (PCI) and finally the synchronicity between stations was tested with an Kruskal Wallis (KW) test. The MK-test shows an increasing trend in precipitation for all stations even if this trend is not significant. This increase resulted in a general increase in the amount of rain received in the area. The analysis of rainfall data revealed a moderate intra and inter annual variability (CoV± 20%). The PCI also revealed an irregularity of rainfall due to its high seasonality. The analysis of variance highlighted an asynchrony of the stations. These results provide an in-depth understanding of the recent rainfall variation and trend in the cotton zone of Mali.*

***Keyword*— Rainfall, variability, trend, PCI, Cotton production zone of Mali**

## I. INTRODUCTION

Rainfall is one of the most key climate parameters which regulate and determine farming activities and production worldwide (Bekele et *al.* 2017; Mesike and Agbonaye, 2016). Agricultural boost in terms of high yield is based on sufficient amount and distribution of rainfall all through the seasons in any region (Zachariah et *al.* 2020). Consequently, in most African countries whose farming activity is mostly rainfed, robust and accurate estimation of the spatial and temporal distribution of rainfall including its trend are vital input parameters in order to secure sustainable agricultural activities (Ayalew et *al.* 2012). The change in rainfall regime can't be assessed easily due to meteorological processes but long-term rainfall could scale up the planning of agriculture in the rainfed region (Pradhan et *al.* 2020).

Located in West Africa (WA), Mali is a landlocked country located populated with about 22.6 million of habitants (World Bank, 2022). The country is large with 1 245 000 km$^2$ and shares a border with seven countries (Algeria, Mauritania, Senegal, Guinea, Côte d'Ivoire, Burkina Faso and Niger). The country spans with four climatic zones from north to south (Sahara Desert, Sahelian, Sudanian and pre-Guinean). Agricultural activities including farming, herding and fishering, are the main activities and employ about 80% of the population and contribute about 36% to the GDP (Maiga et *al.* 2019). Given the fact that Malian agricultural activities are largely dependent on rainfed-agriculture, analysis of long-term historical rainfall data is imperative. These analyses will provide robust information on the distribution of precipitation on one hand and better prepare farmers on extreme events mitigation to avert agricultural losses on the second hand.

The high inter-annual rainfall variability in space and time is one of the most relevant characteristics of West Africa in general and the southern zone of Mali in particular. This is exhibited by variable onsets of the rainy season, somewhat more predictable endings, and droughts or excess water occurrence at any time during the growing season. A number of studies on the contemporaneous debate (e.g. Traore et *al.* 2021; Sanogo et *al.* 2015; Giannini, 2015) show that rainfall increased in the Sahel following the severe drought of the 1980s. Conversely, other researchers believe that the Sahel experienced drought throughout the 1990s (L'Hote et *al*. 2003; Nicholson et *al*. 2000). It is required to understand rainfall variability and trend at the temporal characteristics at local scale in order to gain a clear understanding of rainfall patterns. In this regard, long term study of rainfall pattern and its variability is imperative. Specially, in agricultural regions such as CPZ alteration in the rainfall patterns may have a major impact on the life and livelihood of people. With rapid climate change it becomes more imminent to study the trends in rainfall especially for those parts of the country which have higher dependability on agriculture. In this line, the present study seeks to investigate the recent variability and trend of rainfall and its distribution using 39-years (1983-2021) rainfall time series data for 10 selected weather stations in the cotton production zone (CPZ) of Mali.

## II. MATERIAL AND METHODS

### 2.1. Site description

The cotton production zone (CPZ) of Mali is located between 3°59'02" and 10°36'09" West longitude and 10°09'45" and 14°23'13" North latitude (Figure 1) with a coverage of 150,000 km$^2$ and an estimated population of 8 million habitants in 2017 (Soumare and Traore, 2019). The CZ extends from the Sahelian (300-700 mm) in the north, Sudanian (700-1200 mm) in the centre to the Sudano-Guinean (1200-1600 mm) eco-climatic zone in the south. The spatial distribution of vegetation is largely related to cumulative (annual) rainfall and the length of the rainy season, which varies along the eco-climatic gradient. Vegetation patterns on a landscape scale are determined by localised climatic variations and human activities such as bush clearing and deforestation for agricultural or energy purposes, overgrazing and gold mining. The cotton production in the area is led by the Malian Company for the Development of Textiles (CMDT), spatially organised into 4 subsidiaries, 41 sectors and 520 zones of agricultural production involving more than 4,000 villages. Smallholder farming is the most common agricultural practice in the region. Millet, sorghum and cotton are primarily cultivated, whilst pastoralism (bovines, goats and sheep) is practised throughout the area. Cotton occupies about 30% of the cropping area, 60% for cereals (maize, sorghum and millet), and only 10% of the land is given over to small crops (cowpeas, soybeans, groundnuts, etc.).

### 2.2. Data description

The World Meteorological Organization (WMO, 2018) recommends an observation period of more than 30 years to ensure the independence of climate data time series to cope with natural climate variability. This fact is because shorter time series are more sensitive to the values at the start and end of the series. Therefore time-series data of rainfall from 1983 to 2021 for ten (10) meteorological stations in the cotton production zone were created. These data were derived from a fusion of satellite rainfall estimates from African Rainfall Climatology version 2 (ARC-2) adjusted with weathers stations data using the period of overlap of the two data sources then extended over the study period. Calibration procedures are described in Traore, 2024; Traore et *al.* (2022). Table 1 presents the general geographic information of the selected weather stations. These stations called reference weather stations in this study are those among the 54 stations listed in the area with no more than two (04) years of missing data. This is the criterion that motivated their choice for the present work.

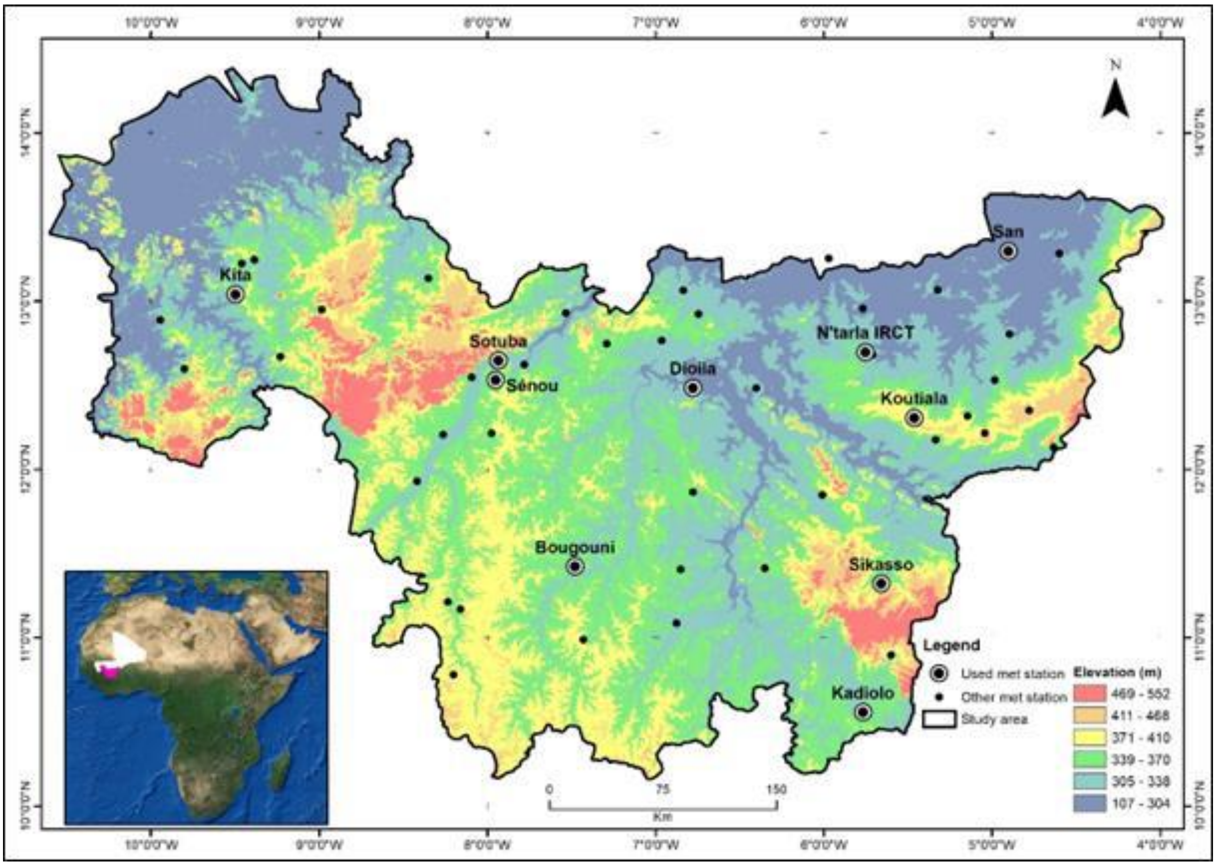


*Fig.1: Relief map of cotton zone with selected weather station's location within the cotton zone of Mali (Source: Traore et al. 2022)*

*Table 1: Selected weather stations of the cotton zone and their general geographic information.*

| Code | Station name | AEZ* | Long (°W) DDMMSS | Lat (°N) DDMMSS | Altitude (m) |
|---|---|---|---|---|---|
| 270131 | Senou | PK | 7°57'00" | 12°31'59" | 373 |
| 270162 | Bougouni | HBN | 7°28'35" | 11°25'34" | 350 |
| 270141 | Dioila | PK | 6°46'32" | 12°29'14" | 309 |
| 270178 | Kadiolo | HBN | 5°45'50" | 10°33'34" | 353 |
| 270107 | Kita | PM | 9°29'43" | 13°02'34" | 349 |
| 270144 | Koutiala | PK | 5°27'38" | 12°18'35" | 411 |
| 270121 | N'tarla IRCT | PK | 5°45'00" | 12°42'00" | 327 |
| 270100 | San | BH | 4°54'03" | 13°18'03" | 284 |
| 270165 | Sikasso | PK | 5°39'26" | 11°19'25" | 355 |
| 270130 | Sotuba | PM | 7°55'589" | 12°39'00" | 315 |

AEZ: Agro-ecological zone; PK: Plateau of Koutiala, HBN: Haut Bani Niger, PM: Mandingo Plateau, BH: Plateau of Bandiagara

### 2.3. Analyse procedures

***Normality test***

Assessment of the normality of data is a prerequisite for selecting the best statistical methods for data analysis. In this regard, the available two main methods for assessing normality are graphical and numerical including statistical tests (Machin et *al.* 2007; Bland et *al.* 2015). This study applied a normality test using the Kolmogorov-Smirnov test (KS-test) method. KS-test is recommended when sample size is greater than 50 (Mishra et *al.* 2019). In such, daily, monthly and annual rainfall for all the stations were subjected to normality tests. The null hypothesis states that data are taken from a normal distributed population and when $P > 0.05$, null hypothesis is accepted and data are called as normally distributed.

***Coefficient of Variation (CoV)***

The study uses CoV to examine the variability in rainfall. The higher value of CoV is an indicator of larger rainfall variability, and vice versa. The equation of CoV is as follows:

$$CoV = \frac{\theta}{\mu} \times 100 \quad (1)$$

Where CoV is the coefficient of variation; $\boldsymbol{\theta}$ is the standard deviation and $\boldsymbol{\mu}$ is the mean of rainfall over the studied period. CoV was computed to classify the degree of rainfall variability according to El-Mahdy, 2021 and Hael, 2021. CoV less than 20 indicate low variability, CoV greater than 20 and less than 30 indicate moderate variability; and CoV greater than 30 indicate high variability (Royé and Martin-Vide, 2017).

***Mann Kendall trend test***

From the wide types of trend analysis methods, this study uses the non-parametric Mann-Kendall trend test (Mk-test) proposed by Mann (1945) and Kendall (1975). This test does not require the data to be normally distributed and has low sensitivity in abrupt breaks due to inhomogeneous time-series (Tabari et *al.* 2011) and have been widely employed to detect monotonic trends in the time series of hydrometeorological variables (Asfaw et *al.* 2018; Xu et *al*. 2018; Zakwan and Ara, 2018; Mohamed and El-Mahdy, 2021; Mohamed et *al.* 2022). The MK test is grounded on a null hypothesis ($H_0$), which indicates that there is no trend-the data are independent and randomly ordered-and this is verified against the alternative hypothesis (Ha), which supposes that there is a trend (Koudahe et *al*. 2018). In the calculation, the value of Z is the judgement criterion for the trend change (Xu et *al*. 2018). When $|Z| \leq 1.96$, the null hypothesis H0 is accepted, indicating that there is no significant trend at the 0.05 significance level. $|Z| \geq 1.96$ demonstrates the trend of the time series is statistically significant. It must be noted that a positive Z indicates that the sequence has an increasing trend, while a negative Z reflects a declining trend.

***Precipitation concentration index***

Precipitation Concentration Index (PCI) was used to assess the monthly heterogeneity of rainfall amounts. PCI is a useful indicator to determine the precipitation changes of a specific region and defined as the ratio between sum of squared monthly rainfall to the square of annual rainfall (Bhattacharyya and Sreekesh, 2022). The PCI, proposed by Oliver (1980) and further modified by De Luis et *al*. (2011), is used for the calculation of the annual PCI following:

$$\text{PCI} = 100 \times \frac{\sum_{i=1}^{12} P_i^2}{(\sum_{i=1}^{12} P_i)^2} \quad (2)$$

PCI values of less than 10 indicate quite uniform annual distribution of rainfall, values between 11 to 15 denote a moderate rainfall distribution, 16 to 20 denote irregular rainfall distribution and above 20 represent a strong irregularity of rainfall distribution Asfaw et *al.* 2018 and Rahman et *al.* 2019, Pawar et *al.* 2022.

***Comparative analysis between stations***

Comparison of several groups or independent samples requires the application of an appropriate statistical test. In this regard, the common statistical tests are ANOVA for normally distributed samples or groups and the Kruskal Wallis test (KW-test) for non-normally distributed samples or groups (Cabral Júnior and Lucena, 2019). In this study, the KW-test test was used since the hypothesis of the normality distribution of data was rejected at 1% of statistical significance, as verified by the KS-test (*p-value: 0.5*). As the KW-test compares (paired or unpaired) k samples based on the null hypothesis that the median differences within groups are not significant. In this research the groups were formed by daily/annual rainfall data for individual met stations to check the rainfall pattern' similarity and difference (synchronicity and asynchronicity) during the 39 years period. The null hypothesis is that there are no significant differences between the rainfall medians in the pattern in the study area.

## III. RESULTS AND DISCUSSION

### 3.1. Long-term rainfall temporal variability

Statistics of annual rainfall (1983-2021) show a comparatively higher rainfall amount for all the stations. The mean annual amount of rainfall varies from 1223.3 mm with a standard deviation of 272.6 at Sikasso to 745.4 mm with a standard deviation of 155 at San. The maximum rainfall at Sikasso was 1848.3 mm recorded in 2018 and the minimum was 781.0 mm recorded in 2002. In San, the maximum rainfall of the period was 1135.4 mm recorded in

2020 and the minimum was 480.9 mm recorded in 1992. The result of the normality test using KS revealed non-normality in the series for all the ten stations at a significance of 5%. Rainfall amounts show low variability for Kadiolo station (18.8%) and Bougouni station (19.4%). Moderate variability in rainfall is observed in the rest of the stations.

*Table 2: Summary statistics of annual rainfall (mm) of selected weather stations (1983-2021)*

| Station | Min | Median | Max | Average | Standard deviation | CoV (%) |
|---|---|---|---|---|---|---|
| Sikasso | 781.0 | 1155.4 | 1848.3 | 1223.3 | 258.7 | 21.6 |
| Bougouni | 807.5 | 1151.7 | 1790.0 | 1187.7 | 227.8 | 19.4 |
| Kadiolo | 657.4 | 1115.5 | 1892.5 | 1192.5 | 218.7 | 18.8 |
| Dioila | 539.9 | 1024.7 | 1796.8 | 1074.1 | 271.3 | 25.7 |
| Senou | 577.9 | 986.5 | 1597.8 | 1017.7 | 207.1 | 20.4 |
| Kita | 630.2 | 978.9 | 1726.7 | 1033.4 | 226.2 | 22.7 |
| N'tarla | 557.4 | 957.5 | 1608.0 | 977.4 | 236.1 | 24.1 |
| Sotuba | 535.6 | 941.3 | 1562.3 | 982.9 | 199.5 | 20.5 |
| Koutiala | 588.8 | 912.0 | 1587.1 | 953.5 | 261.9 | 26.6 |
| San | 480,9 | 719.0 | 1135.4 | 745.4 | 153.4 | 20.7 |

## 3.2. Rainfall trend

The MK test and Sen's slope had been calculated for the trend analyses on the long period of rainfall data from 1983 to 2021 for the 10 meteorological stations in the zone. The results of trend analyses by the MK-test for the study stations were displayed in Table 2. In the Mann Kendall trend test, a p-value less than 0.05 means a significant trend and a p-value greater than 0.05 means is considered an insignificant or simply no trend (Di Leo et *al.* 2020; Amrhein et *al.* 2019). In general, all the stations showed a positive Sen's Slope (between S Slope= 3.99 and 19.67) indicating at least an increasing rainfall trend. Kita in western zone is the only station which exhibits a non-statistically significant trend (p-value of 0.345 greater than 0.05) with a positive Sen's slope value (Sen's slope = 3.99). The other stations show p-values between p=0.000 and p=0.021 ($p < 0.05$) which makes the trends statistically significant upward trend of total rainfall amount. All the stations show either zero or positive values for Kendall's tau, Mann Kendall parameter (*S*), Variance (*S*) and this is a good sign of the increasing trend of rainfall. These results agreed with the rainfall recovery trend asserted by Lalou et *al.* 2019; Giannini, 2015; Sanogo et *al.* 2015 in West Africa. Indeed, the results are also in agreement with the analysis of Traore et *al.* 2021 who had noticed an increased rainfall trend for the period 1983-2018 using a rainfall time series from one meteorological station in the CPZ of Mali. With these results, one can assume that there is an increasing trend of rainfall amounts over the CPZ, significant at 99%.

*Table 3: Mann-Kendal rainfall trend and Sen Slope for selected weather station (1983-2021)*

| Station | Kendall's tau | Sen Slope | *S* | Var(S) | P-value | Alpha | H0 | Z Value |
|---|---|---|---|---|---|---|---|---|
| Sikasso | 0.34 | 12.01 | 250 | 6832.7 | 0.003 | 0.05 | Rejected | 3.01*** |
| Bougouni | 0.26 | 8.45 | 192 | 6832.7 | 0.021 | 0.05 | Rejected | 2.31** |
| Kadiolo | 0.32 | 10.44 | 238 | 6832.7 | 0.004 | 0.05 | Rejected | 2.87*** |
| Dioila | 0.58 | 19.67 | 432 | 6832.7 | < 0.0001 | 0.05 | Rejected | 5.21*** |
| Senou | 0.46 | 12.04 | 338 | 6832.7 | < 0.0001 | 0.05 | Rejected | 4.08*** |
| Kita | 0.11 | 3.99 | 79 | 6831.7 | 0.345 | 0.05 | Accepted | 0.94 |
| N'tarla | 0.57 | 15.44 | 420 | 6832.7 | < 0.0001 | 0.05 | Rejected | 5.07*** |
| Sotuba | 0.34 | 8.43 | 250 | 6832.7 | 0.003 | 0.05 | Rejected | 3.01*** |
| Koutiala | 0.41 | 11.83 | 302 | 6832.7 | 0 | 0.05 | Rejected | 3.64*** |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| San | 0.43 | 8.58 | 320 | 6832.7 | 0 | 0.05 | Rejected | 3.86*** |

Significance level: *** significant at 0.001; ** significant at 0.05

### 3.3. Precipitation Concentration Index (PCI) Analysis

The variation and distribution in seasonal rainfall signify a significant indicator to appreciate the concentration and sequential distribution of precipitation over a given year. Therefore, the variability and concentration of rainfall for seasonal rain was evaluated using annual PCI based on the monthly rainfall over a 39-year period (1983–2021) for 10 meteorological stations in the cotton zone of Mali. The result shows that the rainfall at the 10 weathers stations falls under two classes of moderate and irregular precipitation concentration. Kadiolo station with a PCI value of 15 is the only station highlighting moderate rainfall distribution. A PCI value between 16 and 20 were observed in the reminder stations denoting an irregular rainfall distribution. These results corroborate with the results of Quenum et *al.* 2020 who had already proven an irregularity of rainfall in the savannah zone because of its more pronounced seasonality.

*Table 4: PCI distribution for the ten stations used during 1983-2021 period*

| PCI distribution | PCI range | Annual |
|---|---|---|
| Uniform precipitation | < 10 | NA |
| Moderate precipitation | 11 to 15 | Kadiolo |
| Irregular | 16 to 20 | Sikasso, Bougouni, Dioila, Senou, Kita, N'Tarla, Sotuba, Koutiala, San |
| Strong irregularity | > 20 | NA |

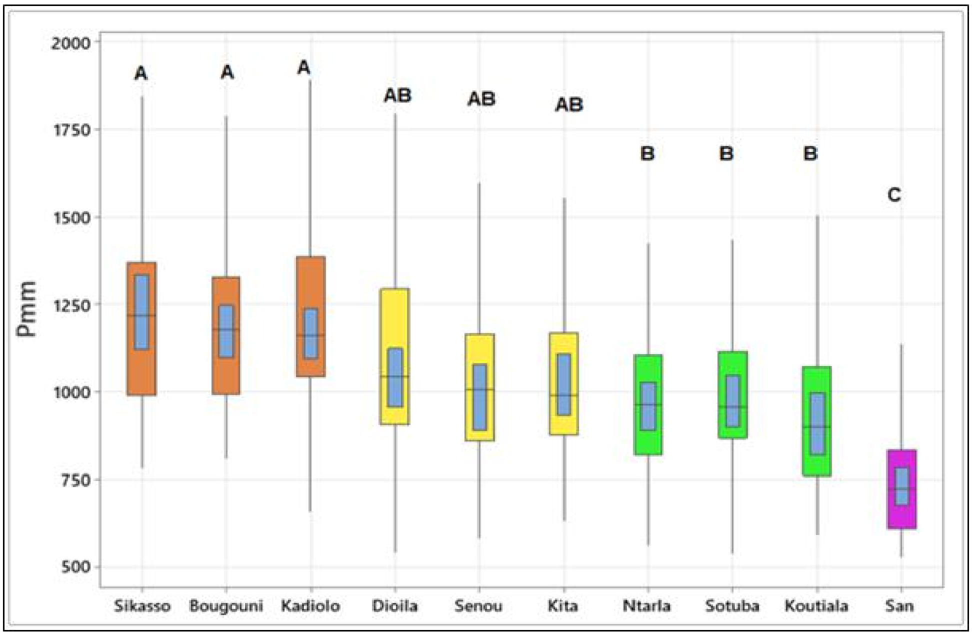


*Fig.2: Boxplot classification of groups weather stations*

### 3.4. Inter-station comparison of rainfall

Figure (3) shows the result of the comparison of the rainfall series of the 10 weather stations. Three homogeneous groups of stations were obtained whose medians are different from each other. The group "A" consists of the stations of Sikasso, Bougouni and Kadiolo with a long-term average rainfall of around 1200 mm with a standard deviation of 253. The group "B" consists of the stations of

N'tarla, Sotuba and Koutiala with a long-term average rainfall of around 971mm with a standard deviation of 231. The "C" group consists only of the station of the station of San with a long-term average rainfall of 745 mm with a standard deviation of 155. The stations of Dioila, Senou and Kita, intermediate group "AB", present almost the same characteristics of the group "A" and the group "B" with a long-term average rainfall of about 1042 mm with a standard deviation of 252. Through this result, one can understand that there is local synchronicity between the stations and not zonal. This means that an increase or decrease in rainfall in any weather station is not widespread for all reminder weather stations in the same climatic zone or even all stations in the study area.

## IV. CONCLUSION

In this paper, an investigation of the rainfall variability and trend in the CPZ of Mali has been performed by the means of daily to annual rainfall dataset from 1983 to 2021. Statistical analysis including CoV, Mann-Kendall non parametric trend test and PCI were carried out in order to detect variability, possible trend and concentration in the rainfall time series data. The rainfall amount showed moderate annual variability. A significant positive trend in total rainfall was observed over the study time period. The PCI showed an irregular rainfall variability in general that corresponds to the characteristic of the savannah zone. The comparison analysis used highlights a synchronicity between some weather stations. Finally, for improving precision and reliability of the application of the findings for practical use, increasing the number of study weather stations would be crucial. However, this research shows the importance of local level study in practical decision-making processes in agriculture and other water management programmes in the climate change adaptation context.

## FUNDING

This research was conducted under AgrECO CML1430 project.

## REFERENCES


[1] Amrhein, V., Greenland, S., McShane, B. (2019). Scientists rise up against statistical significance. Nature 567:305-307 https://doi.org/10.1038/d41586-019-00857-9.

[2] Asfaw, A., Simane, B., Hassen, A., & Bantider, A. (2018). Variability and time series trend analysis of rainfall and temperature in north central Ethiopia: A case study in Woleka sub-basin. *Weather and climate extremes*, *19*, 29-41. https://doi.org/10.1016/j.wace.2017.12.002.

[3] Ayalew, D., Tesfaye, K., Mamo, G., Yitaferu, B., & Bayu, W. (2012). Variability of rainfall and its current trend in Amhara region, Ethiopia. African Journal of Agricultural Research, 7(10), 1475-1486.

[4] Bekele, F., Mosisa, N., & Terefe, D. (2017). Analysis of current rainfall variability and trends over Bale-Zone, South Eastern highland of Ethiopia. Climate Change, 3(12), 889-902.

[5] Bhattacharyya, S., & Sreekesh, S. (2022). Assessments of multiple gridded-rainfall datasets for characterising the precipitation concentration index and its trends in India. *International Journal of Climatology*, 42(5), 3147– 3172. https://doi.org/10.1002/joc.7412

[6] Bland, M. D., Whitson, M., Harris, H., Edmiaston, J., Connor, L. T., Fucetola, R., ... & Lang, C. E. (2015). Descriptive data analysis examining how standardised assessments are used to guide post–acute discharge recommendations for rehabilitation services after stroke. *Physical therapy*, *95*(5), 710-719.https://doi.org/10.2522/ptj.20140347

[7] Cabral Júnior, J., and Lucena, R. (2019). Analysis of Precipitation by Non-Parametric Test of Mann-Kendall and Kruskal-Wallis. *Mercator, 19*. doi:10.4215/rm2020.e19001.

[8] De Luis, M., Gonzalez-Hidalgo, J.C., Brunetti, M. and Longares, L.A. (2011). Precipitation concentration changes in Spain 1946–2005. *Natural Hazards and Earth System Sciences*, 11(5), 1259– 1265. https://doi.org/10.5194/nhess-11-1259-2011.

[9] Di Leo, G., Sardanelli, F. (2020). Statistical significance: p value, 0.05 threshold, and applications to radiomics-reasons for a conservative approach. Eur Radiol Exp 4, 18 https://doi.org/10.1186/s41747-020-0145-y.

[10] El-Mahdy, M. E. S. (2021). Experimental method to predict scour characteristics downstream of stepped spillway equipped with V-Notch end sill. *Alexandria Engineering Journal*, *60*(5), 4337-4346. https://doi.org/10.1016/j.aej.2021.03.018

[11] Giannini, A. (2015). Climate change comes to the Sahel. Nature Climate Change, 5(8), 720-721. https://doi.org/10.1038/nclimate2739.

[12] Hael, M. A. (2021). Modeling of rainfall variability using functional principal component method: a case study of Taiz region, Yemen. *Modeling Earth Systems and Environment*, *7*(1), 17-27. https://doi.org/10.1007/s40808-020-00876-w

[13] Kendall, M.G., (1975). Rank Correlation Methods, *ed. Charles Griffin, London*. Google Sch.

[14] Koudahe, K.; Djaman, K.; Kayode, J.A.; Awokola, S.O.; Adebola, A.A. (2018). Impact of Climate Variability on Crop Yields in Southern Togo. *Environ. Pollut. Clim. Chang.* 2, 148.

[15] L'Hote, Y.A.N.N., Mahe, G.I.L., & Some, B. (2003). The 1990s rainfall in the Sahel: the third driest decade since the beginning of the century. Hydrological Sciences Journal, 48(3), 493-496. https://doi.org/10.1623/hysj.48.3.493.45283.

[16]

[17] Lalou, R., Sultan, B., Muller, B., & Ndonky, A. (2019). Does climate opportunity facilitate smallholder farmers' adaptive capacity in the Sahel? Palgrave Commun 5, 81.

[18] Machin, D., Campbell, M. J., & Walters, S. J. (2007). *Medical statistics a textbook for the health sciences*. John Wiley & Sons, New York. google sch.

[19] Maïga, O., Tounkara, M., Doumbia, S., & Sangho, H. (2019). Mali Political Economy Analysis. Report Research Technical Assistance Center, Washington, DC.

[20] Mann, H. B. (1945). Nonparametric tests against trend. *Econometrica: Journal of the econometric society*, 245-259.

[21] Mesike C.S., Agbonaye, O.E., (2016). Effects of rainfall on rubber yield in Nigeria. *Climate Change*, 2(7), 141-145.

[22] Mishra, P., Pandey, C. M., Singh, U., Gupta, A., Sahu, C., & Keshri, A. (2019). Descriptive statistics and normality tests for statistical data. *Annals of cardiac anaesthesia*, *22*(1), 67. doi: 10.4103/aca.ACA_157_18.

[23] Mohamed, M. A., and El-Mahdy, M. E. S. (2021). Impact of sunspot activity on the rainfall patterns over Eastern Africa: a case study of Sudan and South Sudan. *Journal of Water and Climate Change*, *12*(5), 2104-2124.https://doi.org/10.2166/wcc.2021.312.

[24] Mohamed, M. A., El Afandi, G. S., & El-Mahdy, M. E. S. (2022). Impact of climate change on rainfall variability in the Blue Nile basin. *Alexandria Engineering Journal*, *61*(4), 3265-3275. https://doi.org/10.1016/j.aej.2021.08.056.

[25] Nicholson, S. E., Some, B., & Kone, B. (2000). An analysis of recent rainfall conditions in West Africa, including the rainy seasons of the 1997 El Niño and the 1998 La Niña years. Journal of climate, 13(14), 2628-2640. https://doi.org/10.1175/1520-0442(2000)013<2628:AAORRC>2.0.CO;2

[26] Oliver, J.E. (1980). Monthly precipitation distribution: a comparative index. *Professional Geographer*, 32(3), 300–309. https://doi.org/10.1111/j.0033-0124.1980.00300.x.

[27] Pawar, U., Karunathilaka, P., & Rathnayake, U. (2022). Spatio-temporal rainfall variability and concentration over Sri Lanka. Advances in Meteorology, 2022. https://doi.org/10.1155/2022/6456761.

[28] Pradhan, A., Chandrakar, T., Nag, S. K., Dixit, A., & Mukherjee, S. C. (2020). Crop planning based on rainfall variability for Bastar region of Chhattisgarh, India. Journal of Agrometeorology, 22(4), 509-517.

[29] Quenum, G.M.L.D., Klutse, N.A.B., Alamou, E.A., Lawin, E.A., Oguntunde, P.G. (2020). Precipitation Variability in West Africa in the Context of Global Warming and Adaptation Recommendations. In: Leal Filho, W., Oguge, N., Ayal, D., Adeleke, L., da Silva, I. (eds) African Handbook of Climate Change Adaptation. Springer, Cham. https://doi.org/10.1007/978-3-030-42091-8_85-1.

[30] Rahman, M. S., & Islam, A. R. M. T. (2019). Are precipitation concentration and intensity changing in Bangladesh overtimes? Analysis of the possible causes of changes in precipitation systems. *Science of the Total Environment*, *690*, 370-387. https://doi.org/10.1016/j.scitotenv.2019.06.529.

[31] Royé, D., and Martin-Vide, J. (2017). Concentration of daily precipitation in the contiguous United States, Atmos. Res. 196 (2017) 237-247.https://doi.org/10.1016/j.atmosres.2017.06.011.

[32] Sanogo, S., Fink, A. H., Omotosho, J. A., Ba, A., Redl, R., & Ermert, V. (2015). Spatio-temporal characteristics of the recent rainfall recovery in West Africa. International Journal of Climatology, 35(15), 4589-4605.

[33] Soumaré, M., Traoré, S. (2019). Présentation des zones cotonnières du Mali., Soumaré M. (éd), A*tlas des zones cotonnières du Mali, deuxième édition*, IER-CIRAD, pp 11.

[34] Tabari, H., Marofi, S., Aeini, A., Talaee, P.H., Mohammadi, K. (2011). Trend Analysis of Reference Evapotranspiration in the Western half of Iran. *Agricultural and Forest, Meteorology* 151, 128-136.

[35] Traore, S.S. (2024). Validation des données d'estimation pluviométrique de « African Rainfall Climatology 2 » pour la zone cotonnière du Mali. International Journal of Innovation and Applied Studies, vol. 41, no. 3, pp. 889-896.

[36] Traore, S.S., Soumare, M., Dembele, S., Ojeh, V. N., Guindo, S., & Diakite, C. H. (2021). Assessing Smallholder Farmers' Perception on Climate Variability in Relation to Climatological Evidence: A Case Study of Benguene in the Sudanian Zone of Mali. East African Journal of Agriculture and Biotechnology, 3(1), 24-34. https://doi.org/10.37284/eajab.3.1.380.

[37] Traore, S.S., Guindo, S. Maïga, A.D., Sissoko, S. Soumaré, M. Diakité, C.H (2022). Evaluation et validation des données d'estimation pluviométrique de « African Rainfall Climatology 2 » pour la zone cotonnière du Mali. In : 13ème édition du Symposium Malien sur les Sciences Appliquées (MSAS 2022) ; 31 juillet au 05 août 2022 à Ségou, Mali – Acte en cours d'édition.

[38] World Bank (2022). Country statistics " https://data.worldbank.org/country/mali" visited on 11/15/2023 at 15h31.

[39] World Meteorological Organization; WMO, (2018) Guidelines on the Defintion and Monitoring of Extreme Weather and Climate Events. Task Team Defin Extrem Weather Clim Events. https://doi.org/10.1109/CSCI.2015.171.

[40] Xu, M., Kang, S.C., Wu, H., Yuan, X. (2018). Detection of Spatio-temporal variability of air temperature and precipitation based on long-term meteorological station observations over Tianshan Mountains, Central Asia. *Atmospheric Research.* 2018; 203:141–163. https://doi.org/10.1016/j.atmosres.2017.12.007.

[41] Zachariah, M., Mondal, A., Das, M., AchutaRao, K. M., & Ghosh, S. (2020). On the role of rainfall deficits and cropping choices in loss of agricultural yield in Marathwada, India. Environmental Research Letters, 15(9), 094029.

[42] Zakwan, M., & Ara, Z. (2019). Statistical analysis of rainfall in Bihar. *Sustainable Water Resources Management*, *5*(4), 1781-1789. https://doi.org/10.1007/s40899-019-00340-3.