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Trend Analysis of Annual Precipitation in Southern Benin using Innovative Trend Analysis (ITA) Method

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Authors' contributions

This work was carried out in collaboration among all authors. Author HK designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author AH and WO managed the analyses of the study. Author FH managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Most socio-economic activities depend on the climate. In the context of global climate change, it is crucial to understand how the climate is changing in a country like Benin in order to design effective adaptation responses. This study focused on analyzing the trend of annual precipitation totals in southern Benin.
Study Design: Graphical study.
Place and Duration of Study: Data for this study was collected by Météo-Bénin agency, from 1922 to 2016 across six stations in southern Benin. The selected stations are those with less than ten percent missing data.

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Methodology: The innovative trend analysis method (ITA) and the non-parametric Mann-Kendall test were applied to the data.
Results: The Mann-Kendall test shows that rainfall is stationary in all stations, while the ITA indicates that Adjohoun (slope = 0.792), Bopa (slope = 1.181), and Grand-Popo (slope = 0.734) are experiencing a relatively increasing trend, whereas Pobè (slope = -1.590) and Sakété (slope = -1.156) show a decreasing trend. By category, low totals have not shown any significant trend across the stations, while medium totals are relatively increasing in Adjohoun. As for high totals, they are decreasing at the stations of Abomey, Adjohoun, Grand-Popo, and Sakété, but increasing at Bopa.
Conclusion: The hidden trends revealed by the ITA are important for decision-making, particularly in agriculture and fishing, which are the main activities in the study area.

Keywords: Mann-Kendall; ITA method; climate change; precipitation trend; Southern Benin, West Africa.

2010 Mathematics Subject Classification: 53C25; 83C05; 57N16

1 INTRODUCTION

Due to their immediate and lasting impacts on the natural environment and on humans, issues of climate change and variability have recently become a central concern for scientists and policymakers worldwide. According to the Intergovernmental Panel on Climate Change (IPCC, 2007), climate variability is strongly correlated with climatic variables, particularly precipitation. Thus, mastering changes in rainfall will allow for better management planning and more effective sizing of hydraulic structures.

The most important element in any study on climate change is the search for trends in climatic parameters (Şen, 2014), as it indicates whether the phenomenon is generally increasing or decreasing over time. Traditional methods for identifying trends are limited by often autocorrelated data (Sabzevari et al., 2015). The most commonly used methods are the Mann-Kendall test (Mann, 1945; Kendall, 1975) and the Spearman test (Spearman, 1904). These methods can only show monotonic trends through pure statistical calculations and are unable to identify trends within different value categories in the same series (Wu and Qian, 2017). However, effective and efficient water resource management not only requires identifying trends across the entire series but also within the value categories contained in the series. The magnitude of change and the duration of the period over which changes occur have significantly different implications for planning and managing water resources. It is necessary to consider a profound analysis method capable of revealing hidden trends by using flexible graphical techniques. Recently, the innovative trend analysis method (ITA) introduced by Şen (Şen, 2014) has been widely used to study trends in hydrological and meteorological variables in many regions (Şen, 2014; Wu and Qian, 2017; Şen, 2017, 2012; Caloiero, 2018).

ITA is a simple, intuitive method that can be used independently of distribution assumptions. It has the capacity to identify trends in different subcategories contained within the series (Dong et al., 2020). In Benin, studies on climate trends have been conducted based on statistical calculations using the Mann-Kendall method.

This work focuses on analyzing rainfall trends in southern Benin from 1922 to 2016 following the ITA method. The study aims to analyze annual precipitation totals from 1922 to 2016 across six stations in southern Benin to identify potential changes in rainfall patterns. The second section part presents the data and methods used, and the third, the results and discussion.

2 MATERIALS AND METHODS

2.1 Data and Study Area

The data used in this work consists of daily precipitation collected by Météo-Bénin from 1922 to 2016 in southern Benin. The selected stations are those with less than ten percent missing data. Thus, the study is conducted at six stations, with their coordinates indicated on Fig 1.

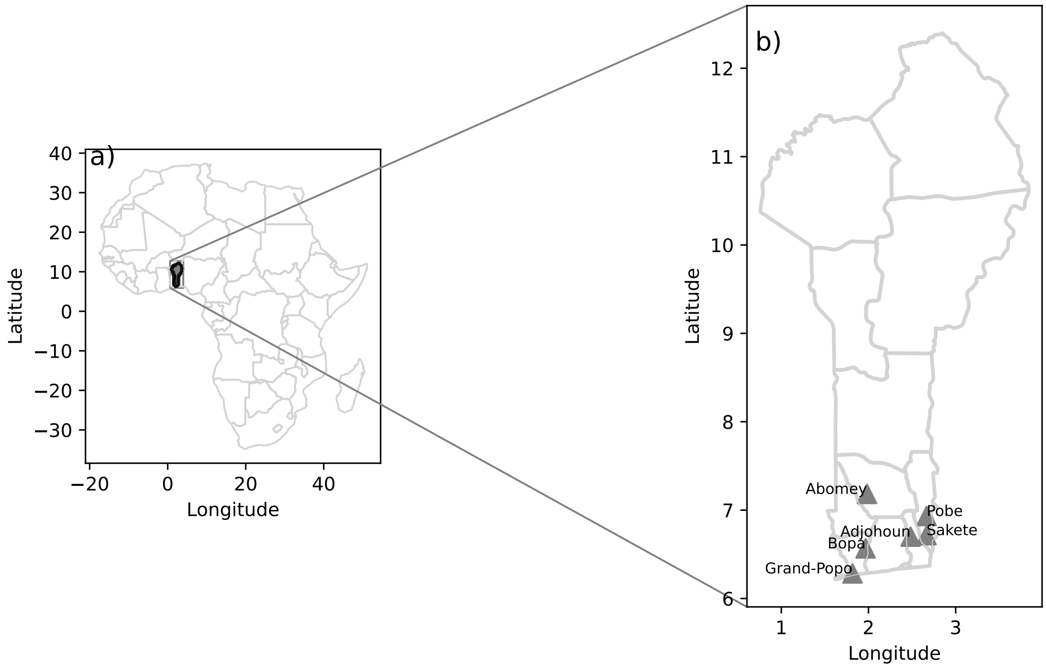

Fig. 1. (a) Benin in Africa and (b) Stations location on the map of Benin

From the daily data, annual totals were calculated on each station. The trend analysis methods described below are applied to the annual totals of each station.

2.2 Trend Analysis Methods

Mann-Kendall Test

The Mann-Kendall test is often used to detect potential gradual changes in hydrological time series. According to Mann (Mann, 1945) and Kendall (Kendall, 1975), this non-parametric test, based on ranks, determines whether the correlation between time and the variable under study is significant or not.

Let $x_1, x_2, ..., x_n$ be a sample of independent values related to a random variable X for which we seek to assess stationarity. The Mann-Kendall statistic Z is defined as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, & \text{if } S < 0 \end{cases} \tag{2.1}$$

with

$$Var(S) = \frac{n(n-1)(2n+5)}{18} \tag{2.2}$$

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} Sgn(x_j - x_k) \tag{2.3}$$

with

$$Sgn(x_j - x_k) = \begin{cases} +1, & \text{if } (x_j - x_k) > 0 \\ 0, & \text{if } (x_j - x_k) = 0 \\ -1, & \text{if } (x_j - x_k) < 0 \end{cases} \tag{2.4}$$

Sgn is the mathematical function that extracts the sign of a real number. Once the sample contains around ten data points, the Z statistic is approximated by a Gaussian distribution. If $Z > 0$, the trend is upward over time, and if $Z < 0$, the trend is downward. The significance of the test is evaluated against a confidence threshold. Thus, the null hypothesis H0 (absence of trend) is rejected when the significance level (p-value) is greater than 5% in this study.

Additionally, when the trend is significant, the magnitude or slope of Sen's estimator for the time series is evaluated using a simple non-parametric procedure developed by Sen (Sen, 1968). The slope is the median of all slopes calculated between each pair of points. It is given by the formula (5):

$$b(mm/an) = mediane(\frac{x_j - x_k}{j - k}), j > k \tag{2.5}$$

Where x_i and x_k are the values of the series at times (i) and (k), respectively. b positive indicates an upward trend in the time series; otherwise, the data series shows a downward trend over the study period.

Innovative Trend Analysis Method (ITA)

The Innovative Trend Analysis method (ITA) is a graphical method that allows for visual and statistical calculation of the trend in a time series. It was introduced by Şen (2014). This method has been used to analyze trends in several meteorological and hydrological series in Turkey (Şen, 2014, 2017) and China (Wu and Qian, 2017).

According to ITA, the time series is divided into two equal parts, and the two sub-series are ordered separately in ascending order. Based on the Cartesian coordinate system, the first sub-series (x) is placed on the X-axis, and the second sub-series (y) is placed on the Y-axis. If the data points lie on a 1:1 line (i.e., the two sub-series are equal), there is no trend. Data points above the 1:1 line represent an upward trend, while data points below this line indicate a downward trend. Furthermore, (Elouissi et al., 2016) indicate that ITA allows for the detection of trends in low, medium, and high categories specifically based on the position of the data points. It is important to note that this classification has significant implications: for example, a trend of low precipitation can help anticipate droughts, while a trend of high precipitation can aid in flood management planning. In this study, three categories were defined based on percentiles: low ($< 20^{th}$), medium ($20^{th} - 80^{th}$), and high ($> 80^{th}$). The different categories are separated by dashed lines in the figures. Moreover, (Şen, 2014) defines the magnitude or slope of the trend as the difference between the two sub-series divided by the mean of the first sub-series:

$$p = \frac{2}{n}[\bar{y} - \bar{x}] \tag{2.6}$$

where $\bar{x}$ is the arithmetic mean of the first sub-series and $\bar{y}$ is the arithmetic mean of the second sub-series; n is the number of data points. To avoid losing the last data points, the first observation is rejected if the size of the time series is odd. If the value of p is positive, the time series shows an upward trend; a negative p value means the time series is downward trending. To test the validity of the slope of the trend, a significance test is applied at a 5% threshold. The trend is significant when the slope value is outside the confidence interval (Şen, 2017).

3 RESULTS AND DISCUSSION

Figure 2 presents the mean and standard deviation of the annual totals from the stations. Bopa and Grand-Popo stations are the least rainy, with an average of less than 1000 mm of water per year during the study period. In contrast, Pobe and Sakete stations are the most rainy, with an average total close to 1200 mm. However, the annual total for each station exhibits a variation of approximately 200 mm.

Table 1 presents the results of the Mann-Kendall method applied to the annual totals at each station. It emerges from this table, particularly from the significance level, that no trend can be anticipated across the six stations despite the values of Z and b. These results confirm those of (Ahokpossi, 2018), who observed, for example, that Adjouhoun's annual total does not show a trend.

Table 1. Summary Table of Mann-Kendall Test Values (Z), Sen's Slope, and Significance p-value

Stations	Z	b	p-value
ABOMEY	0.387	0.40	0.70
ADJOHOUN	1.93	2.072	0.054
BOPA	1.870	1.693	0.06
GRAND-POPO	1.88	1.95	0.06
POBE	-0.315	-0.283	0.752
SAKETE	1.045	1.198	0.295

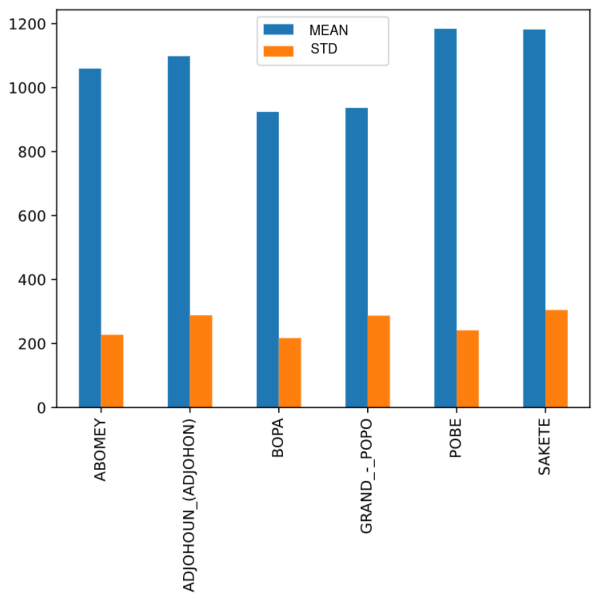

Fig. 2. Mean and standard deviation of annual precipitation at the Stations

Table 2. Summary table of (Şen, 2017) slope values and confidence interval limits

Stations	p	interval limits
ABOMEY	-0.256	± 0.262
ADJOHOUN	0.792	± 0.423
BOPA	1.181	± 0.111
GRAND-POPO	0.734	± 0.424
POBE	-1.59	± 0.200
SAKETE	-1.156	± 0.310

As Mann-Kendall test, ITA test is applied at each station and Şen slope is determined (Table 2). Significant trends are noted. Analyzing the table, we see that the slope (p) is outside the confidence interval for all stations except for Abomey, which confirms the significance of the trends at these stations. Thus, Adjohoun, Grand-Popo, and Bopa show an upward trend, while Pobè and Sakété exhibit a downward trend.

By analysing Fig. 3, it has been revealed that the trend is not uniform along the 1:1 line. This inconsistency makes it challenging to determine the overall nature of the trend. Therefore, a class-based analysis, as suggested, is beneficial for better understanding these trends. The analysis indicates that high cumulative rainfall totals are generally decreasing across all monitoring stations, except for Bopa, where the trend is upward. In terms of average annual rainfall, there is a significant increase observed in Bopa, Grand-Popo, and Adjohoun. Conversely, low cumulative rainfall totals are significantly declining only in Pobe.

3.1 Discussion

The study illuminates the complexity of rainfall trends across different stations in Southern Benin. Last studies conducted in southern Benin, such as the work by (Ahokpossi, 2018), generally indicate a lack of discernible trends in precipitation. However, the ITA test applied in this study uncovers hidden trends in annual rainfall data. The observed decline in high rainfall totals across most monitoring stations contrasts sharply with (Descroix et al., 2015), who claim a gradual return of precipitation in West Africa. The upward trend in high

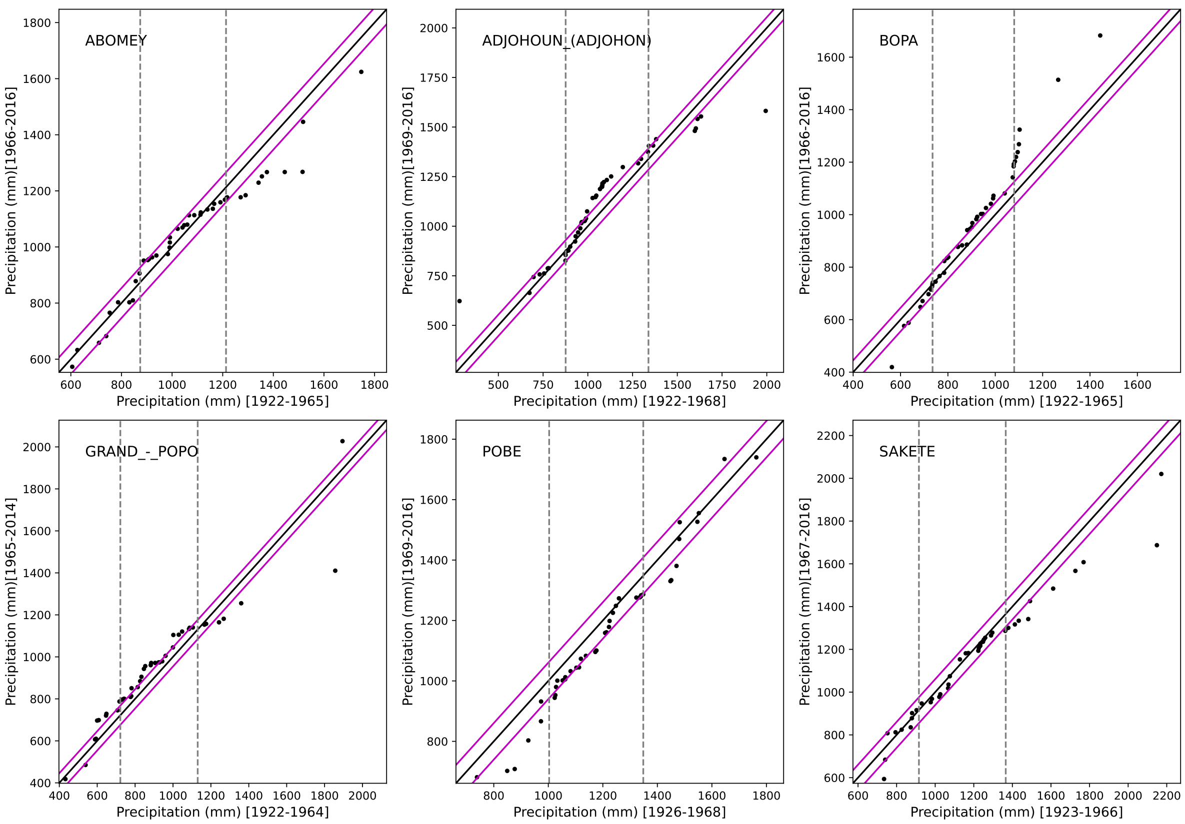

Fig. 3. Mean and standard deviation of annual precipitation at the Stations

annual rainfall totals at Bopa may be attributed to its proximity to Lake Ahémé, suggesting local hydrological influences.

These rainfall trends carry significant implications for the region. Years with substantial rainfall can expose populations to various risks, including crop losses, livestock drowning, building collapses, and falling trees. This can create a cycle of vulnerability for local communities.

The decline in high cumulative rainfall suggests an overall decrease in precipitation, indicated by the rising average rainfall reported at most stations. This phenomenon can adversely affect agriculture, leading to reduced food production (Omoyo et al., 2015; Mapfumo et al., 2020; Kinda and Badolo, 2019).

In light of these challenges, adjusting agricultural practices is essential (Yegbemey et al., 2014; Quenum et al.). An integrated approach, as advocated by (Egah et al., 2023), is crucial. Collaboration among NGOs, farmer associations, and researchers can foster the development of effective adaptation strategies tailored to the specific needs of local communities.

4 CONCLUSION

This study highlighted the ability of the innovative climate trend analysis method to identify hidden precipitation trends in southern Benin, whereas the traditional Mann-Kendall test showed no trend. The interplay between observed rainfall trends and their socio-economic impacts underscores the necessity for proactive measures in agricultural practices and community resilience strategies. Addressing these challenges collectively can help mitigate risks and ensure food security in southern Benin.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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