Journal of Geoscience and Environment Protection, 2023, 11, 155-172
https://www.scirp.org/journal/gep
ISSN Online: 2327-4344
ISSN Print: 2327-4336

Investigation into Recent Temperature and Rainfall Trends in Mali Using Mann-Kendall Trend Test: Case Study of Bamako

Alikalifa Sanogo[1*], Roland Songotu Kabange[1], Prince Appiah Owusu[1], Bakary Issa Djire[2], Racheal Fosu Donkoh[1], Nasser Dia[1]

[1]Department of Civil Engineering, Faculty of Engineering and Technology, Kumasi Technical University, Kumasi, Ghana
[2]Department of Mathematical Sciences, Clark Atlanta University, Atlanta, USA
Email: *AlikalifaSanogo@gmail.com

How to cite this paper: Sanogo, A., Kabange, R. S., Owusu, P. A., Djire, B. I., Donkoh, R. F., & Dia, N. (2023). Investigation into Recent Temperature and Rainfall Trends in Mali Using Mann-Kendall Trend Test: Case Study of Bamako. *Journal of Geoscience and Environment Protection, 11,* 155-172.
https://doi.org/10.4236/gep.2023.113011

Received: February 16, 2023
Accepted: March 26, 2023
Published: March 29, 2023

Abstract

Rainfall and temperature variability analysis is important for researchers and policy formulators in making critical decisions on water availability and use in communities. The Western Sahel, which comprises Mali is considered as one of the vulnerable regions to climate change, and also encountered the challenges of climatic shocks such as flood and drought. This research therefore sought to investigate climate change effects on hydrological events and trends in Sahelian rainfall intensity using Bamako (Mali) as a case study from 1991 to 2020, as limited data availability did not allow an extended period of study. Monthly observed data provided by MALI-METEO was used to validate daily rainfalls data from African Rainfall Climatology Version 2 (ARC2) satellite-based rainfall product on monthly basis. The validated model performance used Nash-Sutcliffe Efficiency (NSE) and Percent Bias (PBAIS) and gave results of 0.904 and 1.0506 respectively. Trends in annual maximum temperatures and rainfalls were analyzed using Mann-Kendall trend test. The result indicated that the trend in annual maximum rainfalls was decreasing, while annual total rainfall was increasing but not significant at 5% significance level. The rate of increase in annual total rainfalls was 0.475 mm/year according to the observed annual rainfall series and decreased to 0.68 mm/year in annual maximum. The analysis further found that annual maximum temperatures were increasing at the rate of 0.03˚C/year at 5% significance level. To provide more accurate climate predictions, it is recommended that further studies on rainfall and temperature with data sets spanning 60 - 90 years be carried out.

Keywords

Sahel Countries, Bamako, Recent Trends, Mann-Kendall Trend Test, Climate

Change

1. Introduction

Many disasters often occur all over the world due to climate change effects on the environment, and these could persist if greenhouse gases, principally CO_2, emission into the atmosphere is not reduced or controlled. About tens of billions of tons of CO_2 are emitted every year by the combustion of coal, oil, and gas (van Ypersele, 2006). Macebo and Madaleno (2023) found that there is a positive effect of CO_2 emission in the rise of global temperature. The Intergovernmental Panel on Climate Change (IPCC) report revealed that climate change affects the ecosystem, human health, water resources, food chain and the world's vulnerable population (IPCC, 2022). Almost all West African countries experienced many devastating effects due to the variability of climate change such as floods of unprecedented magnitude over the past five (5) years (Panthou et al., 2014). Some of the major floods reported since the beginning of the Niamey station observation in 1929 are the 2010 and 2012 floods which caused catastrophic damage to the livelihood and housing infrastructure of the communities living close to river Niger (Abrate et al., 2013). The 2009 Ouagadougou inundation when 263 mm rainfall was measured over a ten (10)-hour period killed eight (8) people, destroyed major infrastructure including a main hospital, and displaced about 150,000 inhabitants (Abrate et al., 2013). Again, heavy rains in Bamako, Mali, in August 2013 caused the death of 37 people, 280 homes were destroyed, and 20,000 were displaced, which brought to 34,700 the number of people affected (OCHA, 2013). Moreover, after a decade, on May 16, 2019 heavy rainfall caused severe flooding in several parts of the capital, Bamako. Some 140 mm depth of rain fell, and at least sixteen (16) people were killed and several others injured.

Runoff is another important parameter for river morphological studies due to erosion effects leading to changes in the landscape. Rainfall and temperature are undoubtedly the most dominant climatic parameters in the Bamako area, as a significant proportion of agriculture depends on rain. Rainfall and temperature variability effects therefore impact on the socio-economic well-being of the citizens since people largely rely on resources sensitive to rain-fed agriculture and variability of the climate. Some parameters therefore critical to agriculture and future crop production are rainfall and temperature. The type of animals, plants and crops that exist in a location also depends on the annual temperature and rainfall variation in the locality. Consequently, water availability to meet human and crop demand for agriculture, domestic water supply and hydroelectric power generation is a function of rainfall received in the locality (Panda & Sahu, 2019). A recent urban flood report based on rainfall events and trend analysis in Bamako (Mali) found that there was an increasing trend in rainfall from

1982-2019 (Fofana et al., 2022). However, 58% of the total rainfall over the same period was found to be normal rainfall, while extreme rainfall constituted 33.33% (Fofana et al., 2022). While governments must partly be held responsible for these devastating effects of climate change on individuals, communities, and the environment, the population should also be accountable through best practices and attitudes to the same environment they belong.

Despite compelling available evidence of rising temperatures globally, accurate computation of the time trends remains a grey area, global warming estimated at 0.9˚C over the last decade (Panda & Sahu, 2019). In a recent study on trend detection over nine (9) states in North-Eastern United States Karmeshu (2012) applied the Mann-Kendall (M-K) test for annual temperature and found them to be in conformity with a linear trend for the nine (9) north-eastern cities over a 101-year period. Gadedjisso-Tossou et al. (2021) on rainfall and temperature trend analysis using M-K's trend test on rain-fed cereal yields in Northern Togo showed the effectiveness to analyze trend at some significant levels. Trend in long-term temporal data can therefore be perceived using M-K test. The M-K trend test analyzed variation in statistically significance over a given period. The test is based on the null hypothesis (H_0), and an alternative hypothesis (H_a). While the null hypothesis (H_0) specifies the existence of no trend, the alternative hypothesis (H_a) assumes that there is a significant variation in the data over a period (Stephanie, 2016). The M-K trend test is a non-parametric one, and the data should not necessarily be normally distributed (Karmeshu, 2012). It therefore finds application in data sets containing data points more than four (4) but sometimes with the least number of samples. Though the test has more chances of not having a trend, it has higher chance of having a trend if a greater number of data points were considered for the test. The test is broadly applicable to hydrological, climate, environmental data (Alemu & Dioha, 2020).

Long-term and temporal time series are critical in the study and analysis of climate variability and trends (Dinku et al., 2018). However, if long-term temporal data of station based on rainfall observation are missing in climate study, satellite data-based rainfall estimates when calibrated and validated with the observed data can be used for climate prediction. Networks of ground-based rainfall estimates in most of developing countries specially most Sahel countries where climate studies depend on that, have always been relatively sparse, even if they exist, the amount of missing data is becoming high (Hughes, 2006). However, the reliability of those networks data is relatively questionable. The African Rainfall Climatology 2.0 is the precipitation dataset available from 1983 to the present at daily time step centered over Africa at 0.1˚ spatial resolution. The temperature threshold is used to compute cold cloud duration (CCD) from the satellite thermal infrared (TIR) images, and a simple linear relationship is then used to convert CCD into rainfall amounts (Dinku et al., 2018). The main difference with ARC1 resides in the recalibration of all Meteosat First Generation (MFG) IR data (1983-2005) (Novella & Thiaw, 2013). Results showed that ARC2 is a main enhancement over ARC1, which is a consistent with other long-term datasets, such as the Global Precipitation Climatology Project (GPCP), the Climate Prediction Center (CPC) and the Climate Merged Analysis of Precipitation (CMAP) (Novella & Thiaw, 2013). The 27-year period correlation coefficient of the African Rainfall Climatology Version 2 (ARC2) data and other long-term datasets is about 0.86 (Novella & Thiaw, 2013).

The African Rainfall Climatology Version 2 (ARC2) has some advantages compared to other satellite-based rainfall products for their long-term climatological rainfall datasets. It starts first, with its historical high-resolution rainfall estimates over a daily basis. This high space resolution would help conduct studies of extreme events dry and wet spells the number of rainy days and onset of the number of rainy seasons (Novella et al., 2010). Second, with ARC2, rainfall impacts on water resources management and agriculture can be maintained that remain continuous and homogeneous over time (Novella et al., 2010). Apart from its definition, the African Rainfall Climatology Version 2 product (ARC2) has been considered for many researches as a unique product likened to other long-term climatological rainfall datasets (Novella et al., 2010), because of its high 0.1˚ gridded spatial resolution and its ability to mixture gauge to provide quotidian information on a near-real time basis rainfall estimates over the African continent. The main limitation of the ARC2 is that its data are not available outside the African continent (Dinku et al., 2018).

The African Rainfall Climatology Version-2 (ARC2) data provided by MALI-METEO was therefore used in this climate study, the observed data was used to confirm satellite data based on rainfall estimates (ARC2) at the monthly scale. This research objective was therefore to identify any existing trends in annual maximum daily rainfalls, annual total rainfalls, and annual maximum monthly temperatures data provided by MALI-METEO over the study period applying M-K trend test. Section two (2) provides an overview of the study area, data collection tools, data analysis, results, and discussions are highlighted in Section three (3), and finally conclusion and recommendations were offered in Section four (4).

2. Materials and Methods

2.1. Study Area

Bamako is the capital city of the Republic of Mali, and Mali's administrative center and located at both sides on the bank of Niger river at 8˚0'10''W and 12˚38'21''N (**Figure 1**). The study area has a land area of 245 km^2, and about 1.3 million inhabitants, while the population density is 5300 people per square kilometer (Keita et al., 2020). According to the World Capital Cities accessed on 23/05/2019, the greater Bamako population is about 3.1 million of people with a density of 10,000 people per square kilometer. The climate can be described as one rainy season, which lasts almost up to six (6) months from the middle of May to October each year, peaking usually in August. The dry season however,

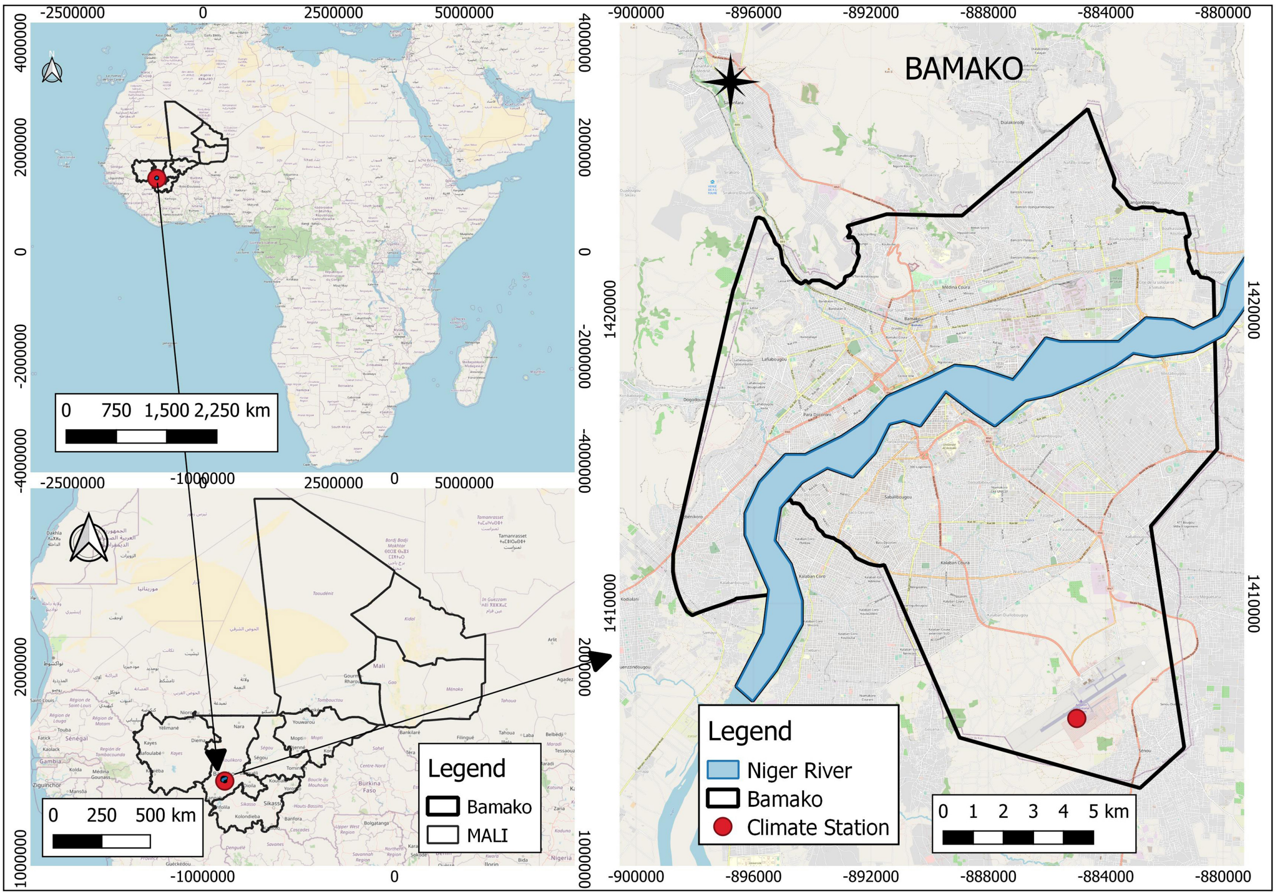

Figure 1. Study area map (Bamako) and climate station location.

occurs between February and the second week of May. Bamako is part of the Sudanian zone in Mali, and has sufficient rainfall, fertile soils, and abundance of trees. Rainfall is largely controlled by Intertropical Convergence Zone (ITCZ) oscillations across the North and South of the African continent, usually bringing rainfall to South Mali from June to October each year (World Bank Group, 2011).

The average monthly rainfall during the rainy season usually ranges from 54.1 mm in May to 290.2 mm in August, with a mean annual rainfall of 991.3 mm. Daily maximum and minimum temperature variations of 40˚C and 17˚C exist in April and December respectively, with an average annual figure of 29˚C in March. The warmest and coolest months of the year are respectively April and May, and December to January representing the months without rain (Keita et al., 2020). Bamako can receive more than 600 mm of rainfall during the rainy season and flooding is common. Located in a valley covered with sandstone deposits, Bamako has two types of soil: one caused by rock formation, and the other due to lateralization and alluvial formation occupying the primary and secondary river beds and tributaries (Keita et al., 2020). Bamako's vegetation is largely savannah forest and rivers (Keita et al., 2020). The topography of the Bamako area is given in **Figure 2**.

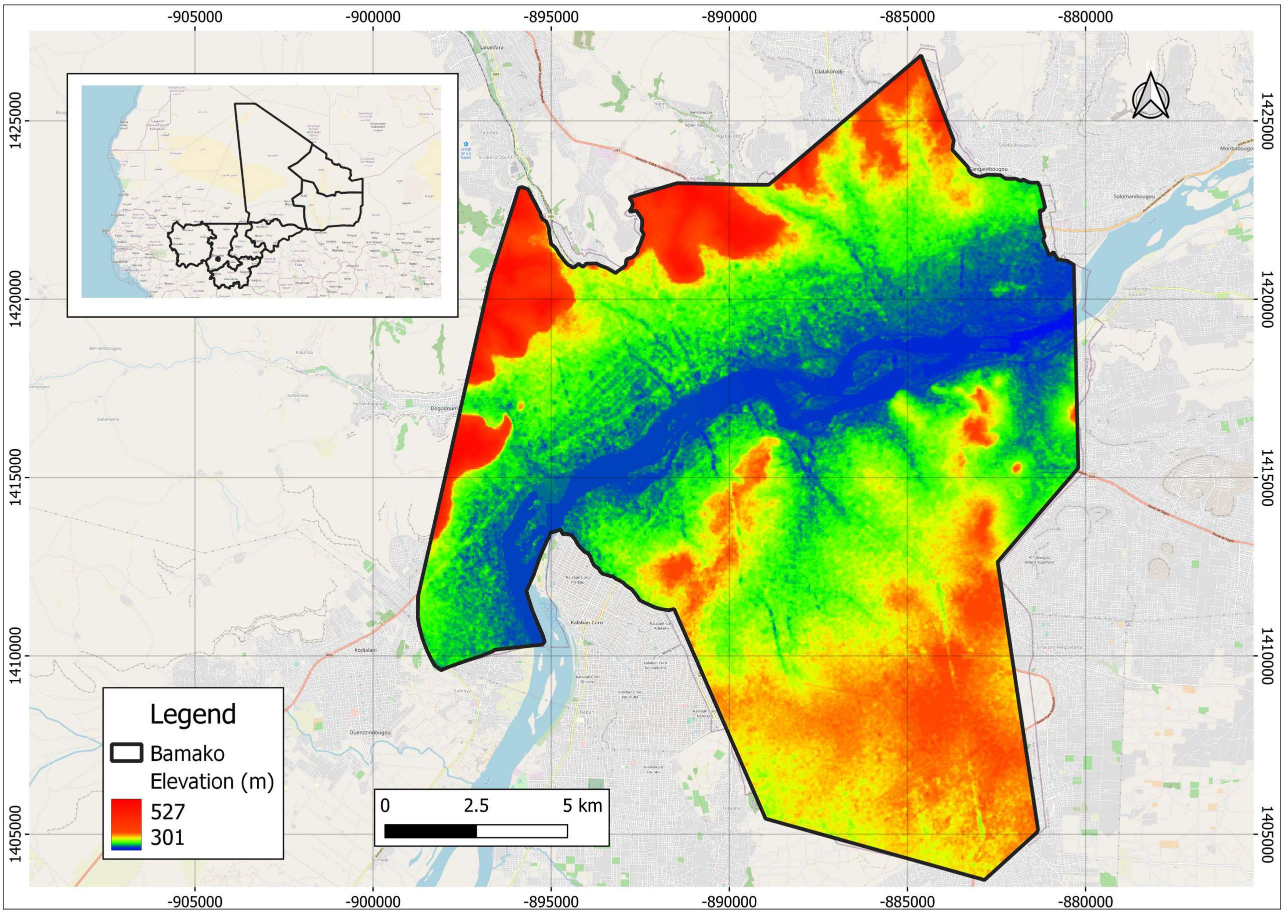

Figure 2. Topography of the study area.

2.2. Data Collection Sources

The study's main data source is the National Meteorological Agency of Mali (MALI-METEO) and it provides monthly rainfall data, monthly maximum and minimum temperatures for a 30-year period from 1991 to 2020. Another source of daily rainfall data was principally extracted using the African Rainfall Climatology Version-2 (ARC2), a satellite product based on rainfall estimate for the period 1991 to 2020 over Bamako. Data provided by MALI-METEO was first used to confirm ARC2 on monthly basis. Bamako-Senou rain gauge station characteristics such as the longitude, latitude and elevation are provided in Table 1. Monthly rainfall data from Bamako-Senou climate station was analyzed statistically to evaluate rainfall variability in the study area (Table 2) using central tendency, dispersion (standard deviation, coefficient of variation) and distribution (skewness and kurtosis).

2.3. Methods

2.3.1. ARC2 Data Validation Using Bamako's Rainfall Station Data

Comparison of a model and its behavior to a real system and its behavior, validated using various statistical methods is critical when using simulated data to produce observed data. The performance of ARC2 data was then used to reproduce

Table 1. Bamako-Senou rain gauge station characteristics.

Station	ID	Longitude	Latitude	Elevation (m)
Bamako-Senou	61291	7.95˚W	12.53˚N	380

Table 2. Descriptive statistics of annual rainfall series in Bamako.

Annual Rainfalls (1991-2020)						
Minimum (mm)	Mean (mm)	Maximum (mm)	Standard deviation (mm)	Coefficient of Variation (%)	Skewness	Kurtosis
750.5	946.77	1205.1	133.374609	14.09	0.311038	−0.987421

Bamako station data for the period 1991-2020. The Nash-Sutcliffe efficiency (NSE), the Pearson's correlation coefficient (r), the coefficient of determination (R^2), the mean absolute error (MAE), the mean square error (MSE) the root mean square error (RMSE) and the percent bias (PBIAS) were used for assessment of the performance of ARC2.

2.3.2. Nash-Sutcliffe Efficiency

Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of residual variance compared to measured data variance (Nash & Sutcliffe, 1970). NSE shows the squared difference between observed and stimulated data. NSE is therefore calculated using the equation below:

$$\text{NSE} = 1 - \left[\frac{\sum_{i=1}^{n} \left(Y_i^{obs} - Y_i^{sim} \right)^2}{\sum_{i=1}^{n} \left(Y_i^{obs} - Y^{mean} \right)^2} \right] \tag{1}$$

where Y_i^{obs}—the i^{th} observation for the evaluated constituent; Y_i^{sim}—the i^{th} simulated value for the evaluated constituent; Y^{mean}—the mean of observed data for the evaluated constituent; and n—the number of observations. NSE varies from $-\infty$ to 1, with NSE = 1 the optimal value. Values between 0 and 1 are considered acceptable levels of performance, while values less than or equal to 0 indicate the observed mean considered better predictor than the simulated value, and indicates unacceptable level of performance (Gupta et al., 1999).

2.3.3. Pearson's Correlation Coefficient (r) and Coefficient of Determination (R^2)

Pearson's correlation coefficient (r) and coefficient of determination (R^2) measure the degree of correlation between measured and simulated data (Moriasi et al., 2007). The coefficients R^2 and r are generally widely used to evaluate models. The correlation coefficient ranges from −1 to 1, and has an index which describes the degree of relationship between observed and simulated data. Whereas no linear relationship exists when $r = 0$, there exist a perfect positive or negative linear relationship when $r = 1$, or −1 respectively. On the other hand, R^2 measures how well a statistical model predicts an outcome (Moriasi et al., 2007). R^2 usually ranges from 0 - 1, and higher R^2 values indicate higher accuracy in the prediction of the outcome. However, values greater than 0.5 are considered acceptable (Santhi et al., 2001; Van Liew, 2003).

Pearson's Correlation Coefficient r is given as:

$$r=\frac{\sum_{i=1}^{n}\left(Y_i^{sim}-\bar{Y}_{Sim}\right)\left(Y_i^{obs}-\bar{Y}_{Obs}\right)}{\sqrt{\sum_{i=1}^{n}\left(Y_i^{sim}-\bar{Y}_{Sim}\right)^2}\cdot\sqrt{\sum_{i=1}^{n}\left(Y_i^{obs}-\bar{Y}_{Obs}\right)^2}} \tag{2}$$

where Y_i^{sim} —the i^{th} simulated value; and $\bar{Y}_{Sim}$ —the mean simulated value; Y_i^{obs} —the i^{th} observed value; and $\bar{Y}_{Obs}$ —the mean observation values.

2.3.4. Errors in Model Evaluation

The mean absolute error (MAE), mean square error (MSE), and root mean square error (RMSE) are used in model evaluation to identify errors in units or squared units that are of consistent interest (Moriasi et al., 2007). RMSE, MAE, and MSE values of 0 indicate a perfect relationship. However, for RMSE and MAE values less than 0.5, the standard deviation of the measured data may be considered low, and that either MAE or RMSE is considered appropriate for model evaluation (Singh et al., 2004).

$$\text{MAE}=\frac{1}{n}\sum_{i=1}^{n}\left|\left(Y_i^{obs}-Y_i^{sim}\right)\right| \quad \text{ranged from 0 to } +\infty \tag{3}$$

$$\text{MSE}=\frac{1}{n}\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{sim}\right)^2 \tag{4}$$

$$\text{RMSE}=\sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{sim}\right)^2} \tag{5}$$

2.3.5. Percent Bias (PBAIS)

Percent bias (PBAIS) is a measure of the average tendency of simulated data to be larger or smaller than the observed counterparts (Gupta et al., 1999). PBAIS has an optimal value of 0, with low-magnitude values indicating accurate model simulation. Positive PBAIS value indicates the model has been underestimated the bias, and a negative PBAIS value indicates the model has overestimated the bias (Gupta et al., 1999). PBAIS computation is by the following equation:

$$\text{PBAIS}=\left[\frac{\sum_{i=1}^{n}\left(Y_i^{obs}-Y_i^{sim}\right)}{\sum_{i=1}^{n}\left(Y_i^{obs}\right)}\right]\times 100 \tag{6}$$

2.3.6. Mann-Kendall (M-K) Trend Test

Studies show that Mann-Kendall (M-K) trend test is one of the most widely used methods for trends detection in climatologic and hydrologic time series (Mavromatis & Stathis, 2011). The test was originally derived by Mann (1945), and the test statistic called Kendall's tau statistic was later derived by Kendall (1975). Evaluation of the M-K test statistic S is by the following equation:

$$S = \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \operatorname{sgn}(x_j - x_i) \tag{7}$$

where,

$$\operatorname{sgn}(x_j - x_i) = \begin{cases} +1, & \text{if } x_j - x_i > 0 \\ 0, & \text{if } x_j - x_i = 0 \\ -1, & \text{if } x_j - x_i < 0 \end{cases}$$

x_j and x_i —the annual values in the j^{th} and i^{th} years.

If $N < 10$, values of |S| are compared directly to the theoretical distribution of S derived by Mann and Kendall. The two (2)-tailed test is used in M-K trend test to know whether trends are significant. The null hypothesis (H_0) is rejected based on the M-K test for the alternative hypothesis (H_a) if the absolute value of $S \geq S_{\alpha/2}$, where $S_{\alpha/2}$ is the smallest S, which has the probability less than α/2 to appear in case of no trend (Karmeshu, 2012).

For $N \geq 10$—S is approximately normally distributed, where the mean and variance are as follows:

$$E(S) = 0 \tag{8}$$

Variance (σ^2) for the S-statistic is computed as follows:

$$\sigma^2 = \frac{n(n-1)(2n+5) - \sum_i^m t_i (i-1)(2i+5)}{18} \tag{9}$$

where t_i—the number of ties to extent i. The summation term is then used only if the data series contains tied values. Note that the standard test Z_s is computed as follows:

$$Z_s = \begin{cases} \dfrac{S-1}{\sigma} & \text{for } S > 0 \\ 0 & \text{for } S = 0 \\ \dfrac{S+1}{\sigma} & \text{for } S < 0 \end{cases} \tag{10}$$

The null hypothesis (H_0) indicates that there is no trend and it is rejected if the calculated value Z_s is greater or equal than some critical value Z_{cr}, where Z_{cr} is given at some significant level α in *p*-value table. Kendall's τ coefficient is a statistic used to measure the association between two variables, and used to determine the existing relationship between two series of data. The Kendall rank correlation coefficient τ is computed as:

$$\tau = \frac{2S}{n(n-1)} \tag{11}$$

2.3.7. Sen's Slope Estimator

The magnitude of trend in M-K trend test is determined by a method derived by Theil (1950) and Sen (1968). The magnitude is computed as follows

$$Q = med\left(\frac{y_j - y_i}{x_j - x_i}\right) \text{ with } j > i \tag{12}$$

3. Results and Discussions

3.1. ARC2 Satellite Product Evaluation

The purpose of this validation work is to assess the performance of ARC2 over Bamako at the local level. Only Bamako station was used to validate the satellite-based rainfall product ARC2. This section therefore describes the approach used and presents validation results at Bamako station as spatial resolution level, and the monthly rainfall data as the temporal scale because daily rainfall data were not provided by the National Meteorological Agency (MALI-METEO). More station data are made available more the correlation coefficient with satellite-based rainfall product is high and then the efficiency of the satellite product may be judged as reliable, normally daily and monthly rain gauge data are judged to be relevant for the validation process.

The relationship between simulated and observed data on monthly basis is given in Figure 3. The results showed that there was almost no statistical difference between the two graphs for most years, the correlation coefficient for the two variables was excellent compared to the standard, as $r = 0.95 > 0.5$ where 0.5 was the minimum acceptable value for (r) and 1 the optimal value of r, the mean bias error also revealed a good performance value compared to the standard value for PBIAS which was in the range of −25% to 25%, the PBIAS found was 1.05%, and the performance value for PBIAS is 0. At the same time, the NSE was 0.90, while the acceptable value for NSE is in the range of 0.75 to 1, and the optimal value being 1. The model is therefore acceptable, as the NSE value less than or equal to zero (0) is considered unacceptable. The MAE, MSE, and RMSE were all in the range of acceptable performance. The coefficient of determination (R^2) which shows the degree of correlation between the observed values and the simulated values was 0.90, which demonstrated a good correlation between two variables. The scatter plot of the ARC2 data and Bamako rainfall data is given in (Figure 4) below. The summary of variables used in this validation process was given in (Table 3) and the summary table for acceptance levels in validation method for models was provided in (Table 4).

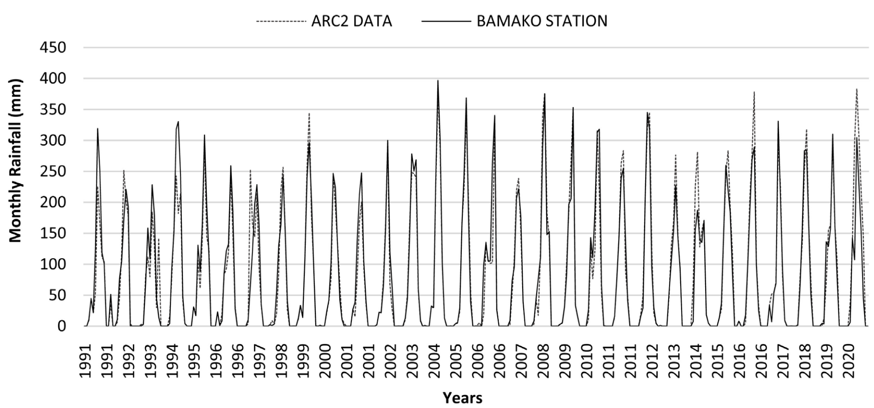

Figure 3. Monthly comparison between ARC2 and Bamako station rainfall data from 1991 to 2020.

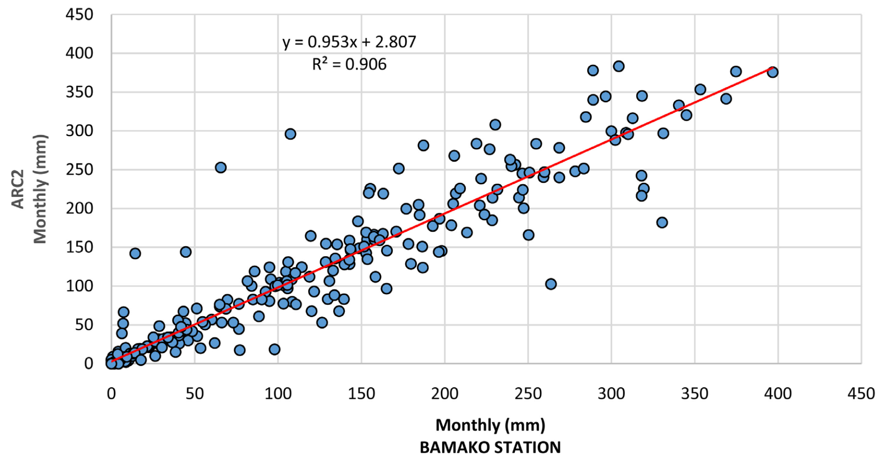

Figure 4. Scatter plot of Bamako station against ARC2 rainfall on monthly basis from 1991 to 2020.

Table 3. Statistical comparison between ARC2 and Bamako station rainfall data.

Statistical indicators	Monthly
Nash-Sutcliffe efficiency (NSE)	0.904399
Mean bias error (PBIAS)	1.0506
Mean absolute error (MAE)	0.828889
Mean square error (MSE)	956.0077
Root mean square error (RMSE)	30.91937
Pearson coefficient of correlation (r)	0.952315
Coefficient of determination (R^2)	0.9069

Table 4. Monthly time step performance ratings for recommended statistic.

Rating	NSE	PBIAS value
Very good	0.75 < NSE ≤ 1.00	PBIAS < ±10
Good	0.65 < NSE ≤ 0.75	±10 ≤ PBIAS < ±15
Satisfactory	0.50 < NSE ≤ 0.65	±15 ≤ PBIAS < ±25
Unsatisfactory	NSE ≤ 0.50	PBIAS ≥ ±25

The validation of rainfall-simulated revealed that all the statistical parameters were found to be in conformity for model performing, the African Rainfall Climatology Version 2 (ARC2) data was then validated with the observed data which can then be used for climate prediction over our period study.

3.2. M-K Trend Test Applied to the Maximum Temperatures

The M-K trend test was applied to the annual maximum temperatures to analyze temperature trend over the study period between 1991 to 2020. The results showed an increasing annual maximum temperature trend since 1991 at 5% significance level. The rate of increase in trend was found to be 0.03˚C/year (**Table 5**) according to the Sen's slope. This finding was in conformity with the linear trend line applied to the annual maximum temperature, (**Figure 5**) which shows that the data used in this study are normally distributed.

However, recent trends on climate variability and change already strongly affect activities in Mali. In a report on climate summaries from World Bank Group (World Bank Group, 2011) across Mali, it was found that the mean annual temperature increased by 0.7˚C since 1960, with an average rate of 0.15˚C/decade. Mali's mean annual temperature was however, projected to increase by 1.2˚C to 3.6˚C in the 2060s, and by 1.8˚C to 5.9˚C in the 2090s, while the rate of warming also was projected to be similar across all seasons (World Bank Group, 2011). Collins et al. (2011) got similar findings, reporting an increased tendency in air temperature in various areas of the World, including the tropical region of Africa. Collins et al. (2011) further found a substantial increase in temperature across Africa, including the Northern Hemisphere, Southern Hemisphere, equatorial, and subtropical regions. Temperatures have risen by more than 0.8˚C across most of Mali since 1975, with average warming rates of more than 0.2˚C per decade (Funk et al., 2012). The rate of increase in annual maximum temperature at the local scale in Bamako was about double that of the national scale in Mali. However, it can be noticed from the study that temperature trends are always of increase in lower scale than higher scale. This finding from the mean annual temperature rate across Mali highlighted this study's finding on the annual maximum temperature at the local scale Bamako, because trend in annual temperature was shown to increase in many parts of Mali (World Bank Group, 2011). Bamako the main activity center of Mali is full of multiple biodiversity and also the place where the Niger river flow (considered as its main surface water

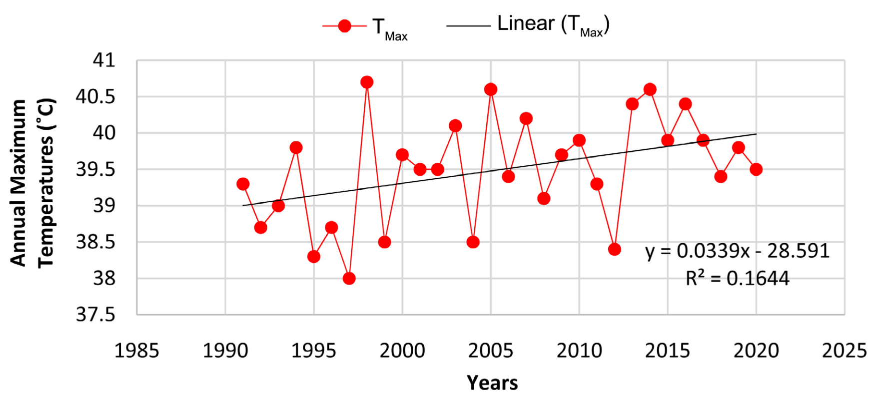

Figure 5. Annual maximum temperatures plot with the linear trend line.

Table 5. Mann-Kendall trend test results for the maximum temperatures from 1991-2020.

Area	Mann-Kendall Statistic (S)	Tau (τ)	Sen's Slope (Q)	Z_s	Significance Level (α)	*P*-value (Two-tailed test)	Test Interpretation
Bamako	107	0.245977	0.030769	1.895781	0.05	0.0287 < 0.05	H_0 rejected

resources), could face significant heat rise on crops, loss of its biodiversity and forest, high evaporation from the Niger river, increasing migration and reduction of its water quality and quantity and therefore could increase health problem related to climate change if temperature rate continues in this magnitude in the future.

This shift to a warmer environment may lower agricultural yields and grazing availability, exacerbating the effect of droughts. According to CEDEAO-Club Sahel/OCDE/CILSS (2008) on climate and climate change, an increasing trend in both maximum and minimum temperatures was observed in the West African Sahel for all three ecological zones (Sudanian, Sahelian, and Sahel-Saharan), with minimum temperature increasing at a quicker rate.

3.3. Mann-Kendall Trend Test Applied to the Annual Maximum Rainfall

The Mann-Kendall trend test was used to determine the annual maximum rainfall trend, the results showed a decreased trend in annual maximum rainfalls, but found to be insignificant at 5% confidence level. The rate at which the magnitude of annual maximum decreased was about 0.68 mm/year (**Table 6**). Annual maximum rainfall trend line is shown in **Figure 6**.

3.4. Mann-Kendall Trend Test Applied to the Annual Total Rainfalls

The Mann-Kendall trend test applied to the annual total rainfalls revealed an increasing trend over the study period (1991-2020) but was not significant at 5% ($p > 0.05$) for the observed annual rainfall data and significant at 5% ($p < 0.05$) for ARC2 data. The magnitude at which trend was increasing according to Sen's slope estimator was about 0.475 mm/year for the observed annual rainfall data

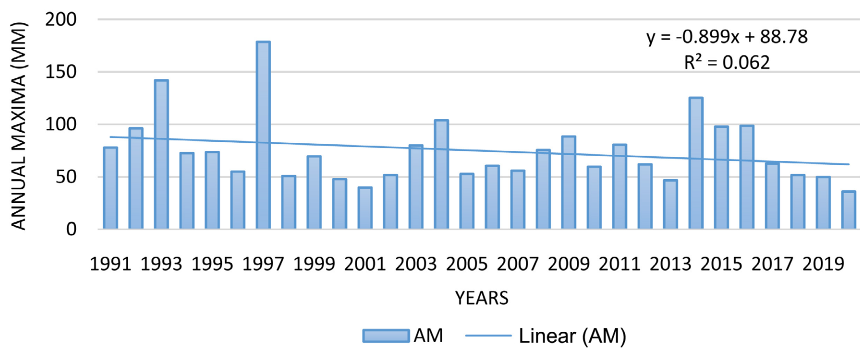

Figure 6. Annual maximum rainfalls plotting with the linear trend line from 1991-2020.

Table 6. Mann-Kendall trend test results for annual maximum rainfalls.

Area	Mann-Kendall Statistic (S)	Tau (τ)	Sen's Slope (Q)	Z_s	Significance Level (α)	*P*-value (Two-tailed test)	Test Interpretation
Bamako	−58	−0.1333	−0.67727	−1.0171	0.05	0.1539 > 0.05	H_0 accepted

and 8.556 mm/year for ARC2 data, respectively (**Table 7**). The magnitude of annual maximum rainfalls was decreasing, and the rainy days substantially increased, this could explain the reason of increase in annual total rainfalls. Annual total rainfall trend line for Bamako-Senou station is given in **Figure 7**.

The M-K trend test found that there was an increasing trend in annual total rainfalls and a decrease trend in annual maximum rainfalls according to linear trend lines. Detecting any existing trend in precipitation or in rainy season in Mali was a subject of much debate and reporting in the past years (World Bank Group, 2011), because Sahel rainfall is characterized by high variation in both annual and inter-decadal basis, and this makes trend difficult to identify and also due to the large model uncertainties in the past year (World Bank Group, 2011). Some inter-models suggested an increasing drought while other individual models predicted humid period related to changing climate (World Bank Group, 2011). Considering large statistical models in these recent years, it has become easier to predict trend in any form of precipitation knowing the long-term record data. Interestingly, the increase of annual total trend in rainfall could if not managed properly lead the Niger River to flooding, last some harvestings and lead some crops to be premature, in other term, could pose serious constraint on the development and security of food in the region Bamako. Change in annual temperatures related to change in annual rainfalls could explain the fact that in term of global warming more excess temperatures leading to more water vapor into the atmosphere, since warmer air can hold water more than cooler air, which therefore has the potential to generate more moisture into the

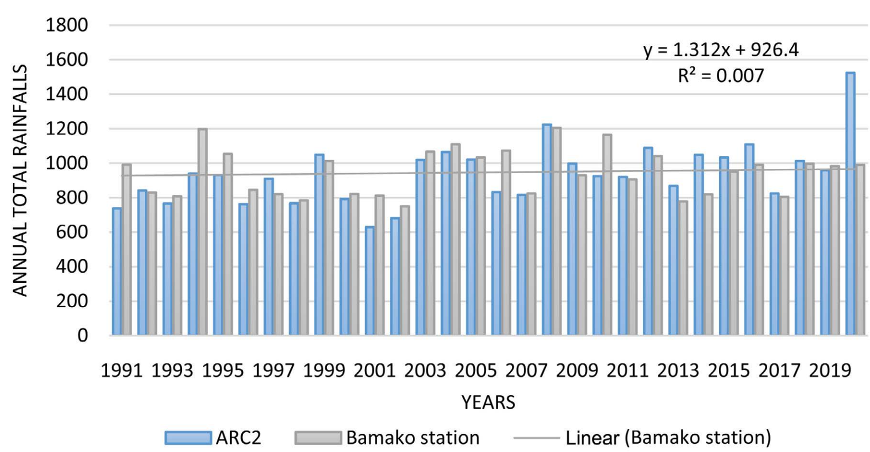

Figure 7. Annual total rainfalls plotting with the linear trend line over the study period.

Table 7. Mann-Kendall trend test results for annual total rainfalls.

Rainfalls data	Mann-Kendall Statistic (S)	Tau (τ)	Sen's Slope (Q)	Z_s	Significance Level (α)	*P*-value (Two-tailed test)	Test Interpretation
Bamako-Senou	9	0.02069	0.475	0.14273	0.05	0.44325 > 0.05	H_0 accepted
ARC2	155	0.35632	8.5556	2.74752	0.05	0.0030 < 0.05	H_0 rejected

atmosphere. It was estimated that extreme rainfall is expected to intensify with increased global warming, and the rate of annual maximum daily rainfall increase was estimated to be between 5.9% and 7.7% per ˚C of globally averaged atmospheric temperature using Clausius Clapeyron equation (Westra et al., 2013).

4. Conclusion

The importance of rainfall and temperature variability analysis to policy makers and researchers in critical decision making cannot be overemphasized. The Mann-Kendall trend test applied to the annual maximum and annual total rainfalls showed a decreasing trend in annual maximum rainfall at 5% significance level and an increasing trend in annual total rainfalls but not significant at 5% significance level according to the observed annual rainfall data. The rate of increase in annual total rainfall was 0.475 mm/year and the rate of decrease in annual maximum rainfall was 0.68 mm/year according to the Sen's slope estimator. Moreover, annual maximum temperature trend is increasing at the rate of 0.03˚C/year, according to M-K trend test and Sen's slope estimator at 5% significance level. Concerning temperature, the linear trend line applied to the data showed the same increasing trend in annual maximum temperature over Bamako with the same rate of increase 0.03˚C/year. Based on the findings of this study derived from the analysis made, it is understood that maximum temperatures across the year in the Bamako area suggest significant variation. In conclusion, therefore, agricultural productivity could be significantly affected by temperature variation across the year.

Beside the urgent need to take deliberate and urgent steps to reduce greenhouse gas emission, it is even more urgent to lessen the use of the planet Earth as if resources were infinite. Again, future global temperature rise can be prevented by recognizing the need to terminate the misuse of nature for exploration. Changes in climate variability, human activities in the physical environment will affect considerably temperatures trends and rainfall intensities. A better understanding of future temperature variation and extreme rainfall intensities was therefore needed to help society adapt to any likely significant changes. The findings of this research are necessary for water resources management, crops production and urban flash floods management in Bamako to mitigate climate change effects on crops and water resources. Moreover, new approaches for adaptation and mitigation are also needed which can translate into a document for policy formulators to take urgent and appropriate decisions. To provide more accurate climate predictions, it is recommended that further studies on rainfall and temperature with data sets spanning 60 - 90 years be carried out.

Acknowledgements

The authors wish to thank Mali's National Meteorological Agency for their support to provide necessary data.

Conflicts of Interest

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

References

Abrate, T., Hubert, P., & Sighomnou, D. (2013). A Study on Hydrological Series of the Niger River. *Hydrological Sciences Journal, 58,* 271-279. https://doi.org/10.1080/02626667.2012.752575

Alemu, Z. A., & Dioha, M. O. (2020). Climate Change and Trend Analysis of Temperature: The Case of Addis Ababa, Ethiopia. *Environmental Systems Research, 9,* Article No. 27. https://doi.org/10.1186/s40068-020-00190-5

Collins, W. J., Bellouin, N., Doutriaux-Boucher, M., Gedney, N., Halloran, P., Hinton, T. Hughes, J., Jones, C. D., Joshi, M., Liddicoat, S., Martin, G., O'Connor, F., Rae, J., Senior, C., Sitch, S., Totterdell, I., Wiltshire, A., & Woodward, S. (2011). Development and Evaluation of an Earth-System Mode—HadGEM2. *Geoscientific Model Development, 4,* 1051-1075. https://doi.org/10.5194/gmd-4-1051-2011

CEDEAO-Club Sahel/OCDE/CILSS (2008). *Climate and Climate Change. The Tlason Regional Integration in West Africa* (p. 13). Environment Series. http://www.oecd.org/fr/csao/publications/40121057.pdf

Dinku, T., Funk, C., Peterson, P., Maidment, R., Tadesse, T., Gadain, H., & Ceccato, P. (2018). Validation of the CHIRPS Satellite Rainfall Estimates over Eastern Africa. *Quarterly Journal of the Royal Meteorological Society, 144,* 292-312. https://doi.org/10.1002/qj.3244

Fofana, M., Adounkpe, J., Larbi, I., Hounkpe, J., Djan'na Koubodana, H., Toure, A., Bokar, H., Dotse, S.-Q., & Limantol, A. M. (2022). Urban Flash Flood and Extreme Rainfall Events Trend Analysis in Bamako, Mali. *Environmental Challenges, 6,* Article ID: 100449. https://doi.org/10.1016/j.envc.2022.100449

Funk, C., Rowland, J., Adoum, A., Eilerts, G., & White, L. (2012). *A Climate Trend Analysis of Mali* (4 p). U.S. Geological Survey Fact Sheet 2012-3105. https://doi.org/10.3133/fs20123105

Gadedjisso-Tossou, A., Adjegan, K. I., & Kablan, A. K. M. (2021). Rainfall and Temperature Trend Analysis by Mann-Kendall Test and Significance for Rainfed Cereal Yields in Northern Togo. *Sci, 3,* Article No. 17. https://doi.org/10.3390/sci3010017

Gupta, H. V., Sorooshian, S., & Yapo, P. O. (1999). Status of Automatic Calibration for Hydrologic Models: Comparison with Multilevel Expert Calibration. *Journal of Hydrologic Engineering, 4,* 135-143. https://doi.org/10.1061/(ASCE)1084-0699(1999)4:2(135)

Hughes, D. A. (2006). Comparison of Satellite Rainfall Data with Observations from Gauging Station Networks. *Journal of Hydrology, 327,* 399-410. https://doi.org/10.1016/j.jhydrol.2005.11.041

IPCC (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability.* Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.

Karmeshu, N. (2012). *Trend Detection in Annual Temperature & Precipitation using the Mann Kendall Test—A Case Study to Assess Climate Change on Select States in the Northeastern United States.* MSc. Thesis, University of Pennsylvania.

Keita, M. A., Ruan, R., & An, R. (2020). Spatiotemporal Change of Urban Sprawl Patterns in Bamako District in Mali Based on Time Series Analysis. *Urban Science, 5,* Article No. 4. https://doi.org/10.3390/urbansci5010004

Macebo, M. & Madaleno, M. (2023). Global Temperature and Carbon Dioxide Nexus: Evidence from a Maximum Entropy Approach. *Energies, 16,* Article No. 277. https://doi.org/10.3390/en16010277

Mavromatis, T., & Stathis, D. (2011). Response of the Water Balance in Greece to Temperature and Precipitation Trends. *Theoretical and Applied Climatology, 104,* 13-24. https://doi.org/10.1007/s00704-010-0320-9

Moriasi, D. N., Arnold, J. G., Van Liew, M. W., Bingner, R. L., Harmel, R. D., & Veith, T. L. (2007). Model Evaluation Guidelines for Systematic Quantification of Accuracy in Watershed Simulations. *Transactions of the ASABE, 50,* 885-900. https://doi.org/10.13031/2013.23153

Nash, J. E., & Sutcliffe, J. V. (1970). River Flow Forecasting through Conceptual Models Part I—A Discussion of Principles. *Journal of Hydrology, 10,* 282-290. https://doi.org/10.1016/0022-1694(70)90255-6

Novella, N. S., & Thiaw, W. M. (2013). African Rainfall Climatology Version 2 for Famine Early Warning Systems. *Journal of Applied Meteorology and Climatology, 52,* 588-606. https://doi.org/10.1175/JAMC-D-11-0238.1

Novella, N. et al. (2010). *African Rainfall Climatology Version 2* (p. 8). Climate Prediction Center.

OCHA (2013). *2013 Rainy Season Overview: West and Central Africa.* http://reliefweb.int/sites/reliefweb.int/files/resources/Rains%20Report%202013%20FINAL%2011092013.pdf

Panda, A., & Sahu, N. (2019). Trend Analysis of Seasonal Rainfall and Temperature Pattern in Kalahandi, Bolangir and Koraput Districts of Odisha, India. *Atmospheric Science Letters, 20,* e932. https://doi.org/10.1002/asl.932

Panthou, G., Vischel, T., & Lebel, T. (2014). Recent Trends in the Regime of Extreme Rainfall in the Central Sahel. *International Journal of Climatology, 34,* 3998-4006. https://doi.org/10.1002/joc.3984

Santhi, C., Arnold, J. G., Williams, J. R., Dugas, W. A., Srinivasan, R., & Hauck, L. M. (2001). Validation of the SWAT Model on a Large Rwer Basin with Point and Nonpoint Sources. *Journal of the American Water Resources Association, 37,* 1169-1188. https://doi.org/10.1111/j.1752-1688.2001.tb03630.x

Sen, P. K. (1968). Estimates of the Regression Coefficient Based on Kendall's Tau. *Journal of the American Statistical Association, 63,* 1379-1389. https://doi.org/10.1080/01621459.1968.10480934

Singh, J., Knapp, H. V., & Demissie, M. (2004). *Hydrologic Modeling of the Iroquois River Watershed Using HSPF and SWAT.* Illinois Department of Natural Resources and the Illinois State Geological Survey. Illinois State Water Survey Contract Report 2004-08. http://www.isws.illinois.edu/pubdoc/CR/ISWSCR2004-08.pdf

Stephanie (2016). *Mann Kendall Trend Test: Definition, Running the Test.* Statistics How To.

Theil, H. (1950). A Rank-Invariant Method of Linear and Polynomial Regression Analysis. *Nederlandse Akademie Wetenchappen Series A, 53,* 386-392.

Van Liew, M. J. (2003). Hydrologic Simulation on Agricultural Watersheds: Choosing between Two Models. *Transactions of the ASAE, 46,* 1539-1551. https://doi.org/10.13031/2013.15643

van Ypersele, J.-P. (2006). L'injustice fondamentale des changements climatiques. *Alter-*

natives Sud, 13, 7-20.

Westra, S., Alexander, L. V., & Zwiers, F. W. (2013). Global Increasing Trends in Annual Maximum Daily Precipitation. *Journal of Climate, 26,* 3904-3918. https://doi.org/10.1175/JCLI-D-12-00502.1

World Bank Group (2011). *Vulnerability, Risk Reduction, and Adaptation to Climate Change.* World Bank Group.