American Journal of Climate Change, 2024, 13, 732-741
https://www.scirp.org/journal/ajcc
ISSN Online: 2167-9509
ISSN Print: 2167-9495

Observed Trends in Daily Hydroclimatic Extremes in West Africa: Comparative Analysis between Niamtougou (Togo) and Zinder (Niger) from 1980 to 2020

Kossi Komi

Regional Center of Excellence on Sustainable Cities (CERViDA-DOUNEDON), University of Lomé, Lomé, Togo
Email: kossik81@yahoo.fr

How to cite this paper: Komi, K. (2024). Observed Trends in Daily Hydroclimatic Extremes in West Africa: Comparative Analysis between Niamtougou (Togo) and Zinder (Niger) from 1980 to 2020. *American Journal of Climate Change, 13,* 732-741.
https://doi.org/10.4236/ajcc.2024.134034

Received: July 16, 2024
Accepted: December 10, 2024
Published: December 13, 2024

Abstract

Climate change is manifested by a modification in the frequency and intensity of extreme climatic phenomena that can cause significant damage to human activities and ecosystems. The objective of this study is to carry out a comparative analysis of the observed evolution of hydroclimatic extremes between the cities of Niamtougou (Togo) and Zinder (Niger) from 1980 to 2020. Daily data on rainfall and temperature (minimum and maximum) were used to calculate six (06) extreme rainfall indices and six (06) extreme temperature indices. Furthermore, the non-parametric Man-Kendhal test and Sen's slope were applied to estimate trends in hydroclimatic extreme indices. The results indicate an increase in all extreme rainfall indices in both Niamtougou and Zinder. As for the indices relating to extreme temperatures, only the frequency of cool days and the frequency of cool nights show a negative trend in these two cities. These results are important for better management of climate risks in the study areas.

Keywords

Evolution, Hydroclimatic Extremes, Niamtougou, Zinder, West Africa

1. Introduction

Climate change is now unequivocal on a global scale and increasingly evident on regional and local scales (IPCC, 2021). Anthropogenic greenhouse gas emissions increase the global average temperature and affect the entire Earth's climate system. Thus, the global average temperature increased by 0.05 (0.15 to 0.15) ˚C per decade between 1998 and 2012, compared to a long-term increase of 0.12 (0.08 to

0.14) ˚C per decade over the period from 1951 to 2012 (IPCC, 2013). In addition, extreme temperatures and rainfall have shown a robust increase in Africa. For instance, February 11-15, 2024, many West African countries experienced severe heatwaves with temperatures above 40˚C (Pinto et al., 2024). In 2023, thirty-two (32) people died, thirty (30) were injured and 110,000 persons were affected by floods caused by torrential rains between June and September[1]. In addition, floods caused by heavy rainfall killed 2,970 and 275 persons respectively in Democratic Republic of Congo and Nigeria.

Furthermore, all the general circulation models (GCMs) used by the IPCC during the Fourth Assessment Report indicate temperature projections in West Africa of around 3.3˚C by the end of the 21st century. Concerning the expected evolution of precipitation amounts in sub-Saharan Africa, the uncertainty is considerably greater and several models do not agree on whether the evolution of precipitation will be negative or positive (Bichet et al., 2020; Cooper et al., 2008).

Climate change is altering the frequency, intensity, extent, duration and timing of extreme weather events with dramatic consequences for food security and economic growth. In West Africa, a number of studies have been undertaken to understand the evolution of climatic extremes. For instance, Audu et al. (2021) explored precipitation extremes over Nigeria from 1973 to 2013 and observed significant negative trends in most of the precipitation indices except the consecutive dry day which showed upward trends in many parts of the country. Halissou et al. (2021) analyzed the variability of extreme temperature events in the Beninese basin of the Niger River for the recent and the near future and revealed significant trends in indices of extreme temperature intensity and those related to the frequency of warm sequences in the past. In Togo, Klassou and Komi (2021) analyze extreme rainfall over the middle Oti River Basin and showed decreasing trends in most of the heavy rainfall indices while the dry spell index exhibited a rising trend in a large portion of the study area from 1921 to 2018. Moreover, Ly et al. (2013) analyzed the evolution of some extreme temperature and precipitation indices over a large area of West African Sahel and showed a negative trend in the number of cool nights, and more frequent warm days and warm spells from 1960 to 2010. However, trends in extreme rainfall indices were not as uniform as the ones in extreme temperatures. In Mali, Touré et al. (2017) assessed the trends in daily temperature and precipitation extremes in two town namely Bamako and Ségou during the period between 1961 and 2014. Their results indicated decreasing trends for cold nights and cold days while warm nights, warm days and warm spells showed insignificant positive trends over the period from 1961 to 2014 in Bamako whereas a positive significant decreasing trends in cool days, cool nights and significant positive trends in warm spells in Ségou. It is important to analyze trends in extreme hydro-climatic phenomena, as this will indicate the nature of adaptation strategies to be implemented to reduce the vulnerability of populations and improve their livelihoods in an economy dominated by rainfed agriculture. However, a little research has been performed to understand the trends of climate

[1]https://www.cajnewsafrica.com/2023/09/01/deadly-floods-exacerbate-niger-crises/

extreme using a combination of climate indices, Man-Kendhal and Sen's slope tests. So, the objective of this study is to carry out a comparative analysis of the observed evolution of hydroclimatic extremes between the cities of Niamtougou (Togo) and Zinder (Niger) from 1980 to 2020.

2. Materials and Method

2.1. Study Area

The study was carried out for the towns of Niamtougou (Togo) and Zinder (Niger) in West Africa (Figure 1). The town of Niamtougou has an area of approximately 21 km^2 and is located in northern Togo. The climate of Niamtougou is tropical and dry with a rainy season (April-October), a dry season (November-March). The average annual rainfall of 1336 mm (1980-2020) whereas the annual average maximum and minimum temperatures are respectively 33.0˚C and 20.94˚C (1980-2020).

The city of Zinder has an area of about 528.3 km^2 and is located in the southern Niger (Table 1). The climate is sahelo-soudanean, with an average annual rainfall of about 420.13 mm (1980-2020). The minimum averages temperatures are recorded in December-January and the maximum in April-May. The monthly maximal temperatures can reach 40˚C and minimal 15˚C (Niger Republic, 2015).

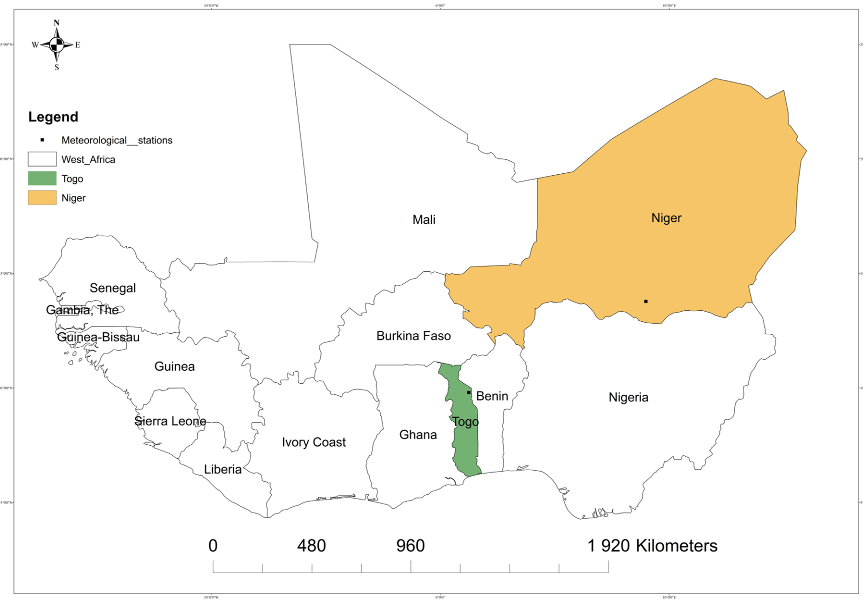

Figure 1. Location of the study area.

Table 1. Location of weather stations.

Synoptic station	Longitude (decimal degree)	Latitude (decimal degree)	Altitude (m)	Country
Zinder	8.98	13.78	458	Niger
Niamtougou	1.25	9.8	462	Togo

2.2. Data and Indices

The daily minimum and maximum temperatures as well as rainfall of the two synoptic stations were collected from the Togolese national agency of meteorology and the directorate of national meteorology of Niger. Firstly, a data quality check was carried out and erroneous data were detected and considered as missing data with a code (−99.9).

All the selected climate indices were calculated annually using the RClimdex 1.0 software (Zhang & Yang, 2004). The indices are calculated for each month if less than 3 days are missing whereas the annual values of the indices are calculated if less than 15 days are missing in a year. In order to improve studies of climate extremes using statistically robust indices covering a wide range of climates, ETCCDI has defined a set of 27 indices that describe the particular characteristics of the extremes, including amplitude, frequency and persistence (Zhang et al., 2011). In this study, six (06) extreme temperature indices and six (06) extreme rainfall indices were selected due to their relevance in the study area (**Table 2**).

Table 2. List of selected climatic extreme indices. (Zhang et al., 2011)

N˚	Indices	Description	Unit
		Rainfall extreme	
1	CDD	Maximum number of consecutive days when precipitation < 1 mm	days
2	CWD	Maximum number of consecutive days when precipitation ≥ 1 mm	days
3	R20mm	Annual count when precipitation ≥ 20 mm	days
4	R95P	Annual total precipitation from days > 95th percentile	mm
5	Rx1day	Monthly maximum 1-day precipitation	mm
6	Rx5day	Monthly maximum consecutive 5-day precipitation	mm
		Temperature extreme	
	TX10p	Percentage of time when daily max temperature < 10th percentile	%
	TX90p	Percentage of time when daily max temperature > 90th percentile	%
	TN10p	Percentage of time when daily min temperature < 10th percentile	%
	TN90p	Percentage of time when daily min temperature > 90thpercentile	%
	TXx	Monthly maximum value of daily maximum temperature	˚C
	TNx	Monthly maximum value of daily min temperature	˚C

2.3. Man-Khendal Test

The non-parametric Mann Kendall test (Mann, 1945) is a statistical test which detects the presence of a linear trend in a time series with a given level of significance. It has both the advantage of being robust to the presence of outliers in the time series and is less sensitive to inhomogeneous data. The test statistic, S, is estimated using the formulae given by Equations 1 and 2:

$$S = \sum_{K=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}\left(x_j - x_k\right) \tag{1}$$

With

$$\operatorname{sgn} = \left(x_j - x_k\right) = \begin{cases} +1 \ if \left(x_j - x_k\right) > 0 \\ 0 \ if \left(x_j - x_k\right) = 0 \\ -1 \ if \left(x_j - x_k\right) < 0 \end{cases} \tag{2}$$

x_j and x_k are data values at times j and k respectively, while n is the number of data points. For $n < 10$, the value of $|S|$ is compared to the theoretical distribution of S derived by Mann and Kendall. In the cases where $n > 10$, the standard normal variable Z is calculated by:

$$Z = \begin{cases} \dfrac{S-1}{\sqrt{VAR(S)}} \ if \ S > 0 \\ 0 \ if \ S = 0 \\ \dfrac{S+1}{\sqrt{VAR(S)}} \ if \ S < 0 \end{cases} \tag{3}$$

Where

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{q} t_p \left(t_p - 1\right)\left(2t_p + 5\right)}{18} \tag{4}$$

q is the number of tied groups while t_p is the number of data values in the pth group. Positive values of Z show an upward trend whereas negative values of Z indicate downward trend. At 0.05 significance level, if $|Z|$ is greater than 1.96 the null hypothesis is rejected, indicating that the trend is statistically significant. In order to estimate the significance of the trends, the P-value, was used to analyse the null hypothesis that the trend is equal to 0. The trend for each index was considered statistically significant when the P-value is less than or equal to found at 0.05.

2.4. Sen's Slope

The Sen's nonparametric approach (Sen, 1968) was used to estimate the slope of an existing trend. It is considered more robust than the least-squares method because of its relative insensitivity to extreme values and better performance even for normally distributed data (Kumar et al., 2017). The Sen's method computes the slope as a change in measurement per change in time (Equation 5). To get the slope estimate Q in equation calculate the slopes of all data value

$$Q_i = \frac{x_j - x_k}{j - k} \ for \left(i = 1, \cdots, N\right) \tag{5}$$

Where, Q_i is the slope between data points xj and x_k; x_j is the data measurement at time j and xk is the data measurement at time k.

For a time series with n observations, there are a possible N = n (n − 1)/2 values of Q_i that can be computed. According to Sen's method, the overall estimator of Sen's slope is simply given by the median of these N values of Qi (Jiqin et al., 2023) as shown in Equation 6:

$$Q_{med} = \begin{cases} Q_{\frac{N+1}{2}} \, if \; N \, is \, odd \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right) if \; N \; is \; even \end{cases} \tag{6}$$

3. Results and Discussion

3.1. Trends in Rainfall Extreme

The observed trends of daily rainfall indices in Zinder (Niger) and Niamtougou (Togo) are shown in **Table 3**. Over the years 1980-2020, all the rainfall extreme indices namely CDD, CWD, R20mm, R95p, Rx1day and Rx5day exhibited a positive trend in both cities. However, only the trends of annual count of daily precipitation ≥ 20 mm, precipitation from days > 95th percentile and monthly maximum consecutive 5-day precipitation are statistically significant at the Zinder station while only the monthly maximum consecutive 5-day precipitation is statistically significant (p-value is less than 0.05) at Niamtougou synoptic station (**Table 3 and Figure 2**). These results are coherent with the results of Barry et al. 2018 who indicated significant upward trends in 5-Day maximum rainfall (RX5day; 7.1 mm/decade), in R95P (28 mm/decade) and in R20mm (0.2 days/decade) during 1960-2010 in West Africa. In addition, Ly et al. (2013) have shown an increase in the cumulated rainfall of extremely wet days in many parts of the West African Sahel. Furthermore, a trend towards wetter conditions was observed from 1961 to 2018 with positive trends of the number of days of precipitation exceeding 10 mm, the maximum of 5 days of precipitation and consecutive wet days in Kara and Atakpamé (Komi et al., 2022). These wetter conditions have caused severe floods in West Africa as it was the cases in Togo (Blakime et al., 2024) and Niger (Elagib et al., 2021).

Table 3. Trends of extreme rainfall indices from 1980 to 2020. In bold, the statistically significant trends. (p-value is less or equal to 0.05)

Indices	Zinder (1980-2020)		Niamtougou (1980-2020)	
	Trends	P-value	Trends	P-value
CDD	0.212	0.599	0.321	0.383
CWD	0.019	0.154	0.047	0.146
R20mm	0.117	0.002	0.039	0.521
R95P	2.392	0.031	1.997	0.24
Rx1day	0.296	0.146	0.281	0.193
Rx5day	0.81	0.017	0.753	0.007

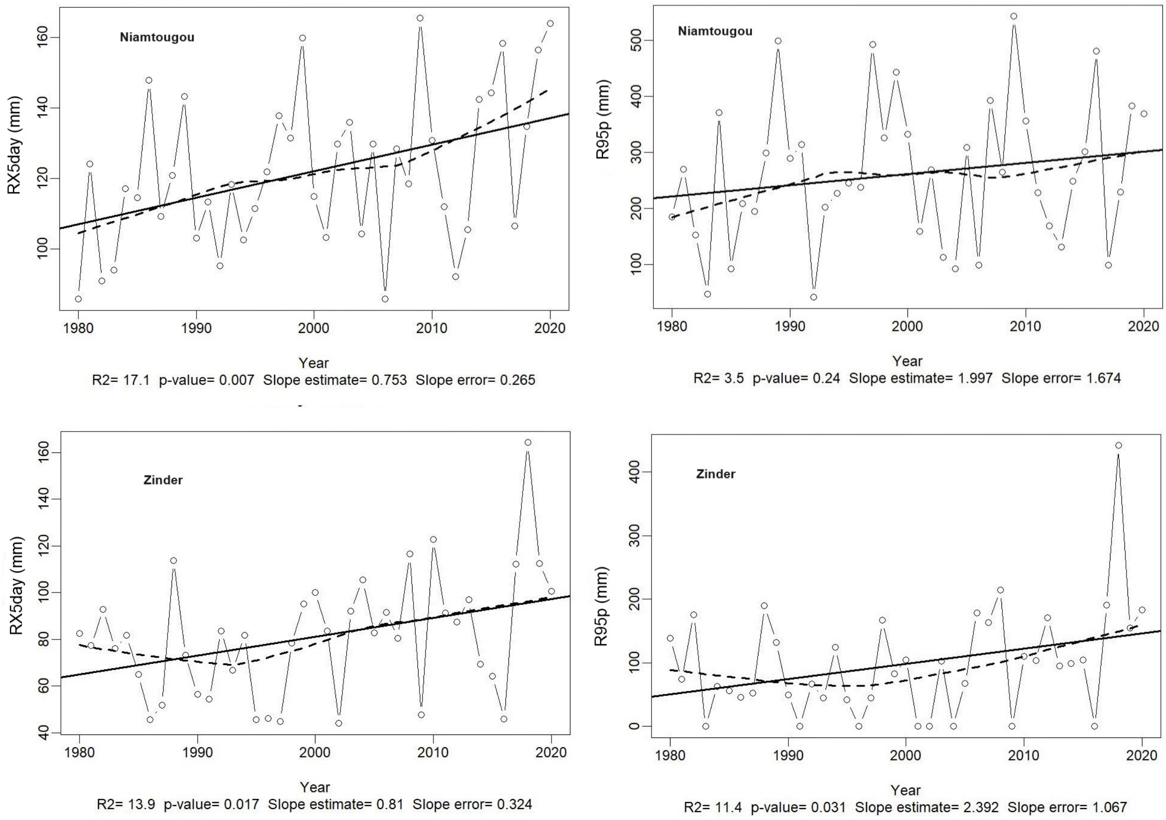

Figure 2. Trends of Rx5day and R95p from 1980-2020. The solid line represents the estimated liner trend while the dot-dashed line represents the polynomial trend line.

3.2. Trends in Temperature Extreme

Table 4 **and** Figure 3 show increasing trends of daily maximum temperature > 90th percentile (TX90p), daily minimum temperature > 90thpercentile (TN90p) and daily maximum temperature (TXx) while the trends of TX10p and TN10p indices are negative for both Zinder and Niamtougou cities. Only the trend of TNx is slightly negative at Zinder but positive at Niamtougou (**Table 4**). The study of Barry et al. 2018 revealed spatially coherent changes of warming in TXx, TXn, and TNn extreme temperature indices in all the selected stations in West Africa from 1961-2010 whereas TX10p and TN10p exhibited significant warning trends only for 62 % and 61 % of the selected meteorological stations respectively. In addition, the study of Halissou et al. (2021) indicated increasing trends in the indices of extreme temperature intensity (TNn, and TXx) as well as in the frequency of warm sequences (TN90p and TX90p) from 1976 to 2010 in the Benin part of the Niger river basin.

Table 4. Trends in extreme temperature indices from 1980 to 2020. (in bold, the significant trends)

Indices	Zinder (1980-2020)		Niamtougou (1980-2020)	
	Trends	P-value	Trends	P-value
TX10p	−0.173	0	−0.191	0

Continued

TX90p	0.233	0	0.194	0.013
TN10p	−0.083	0.028	−0.045	0.585
TN90p	0.061	0.3	0.116	0.161
TXx	0.038	0	0.014	0.173
TNx	−0.002	0.886	0.014	0.266

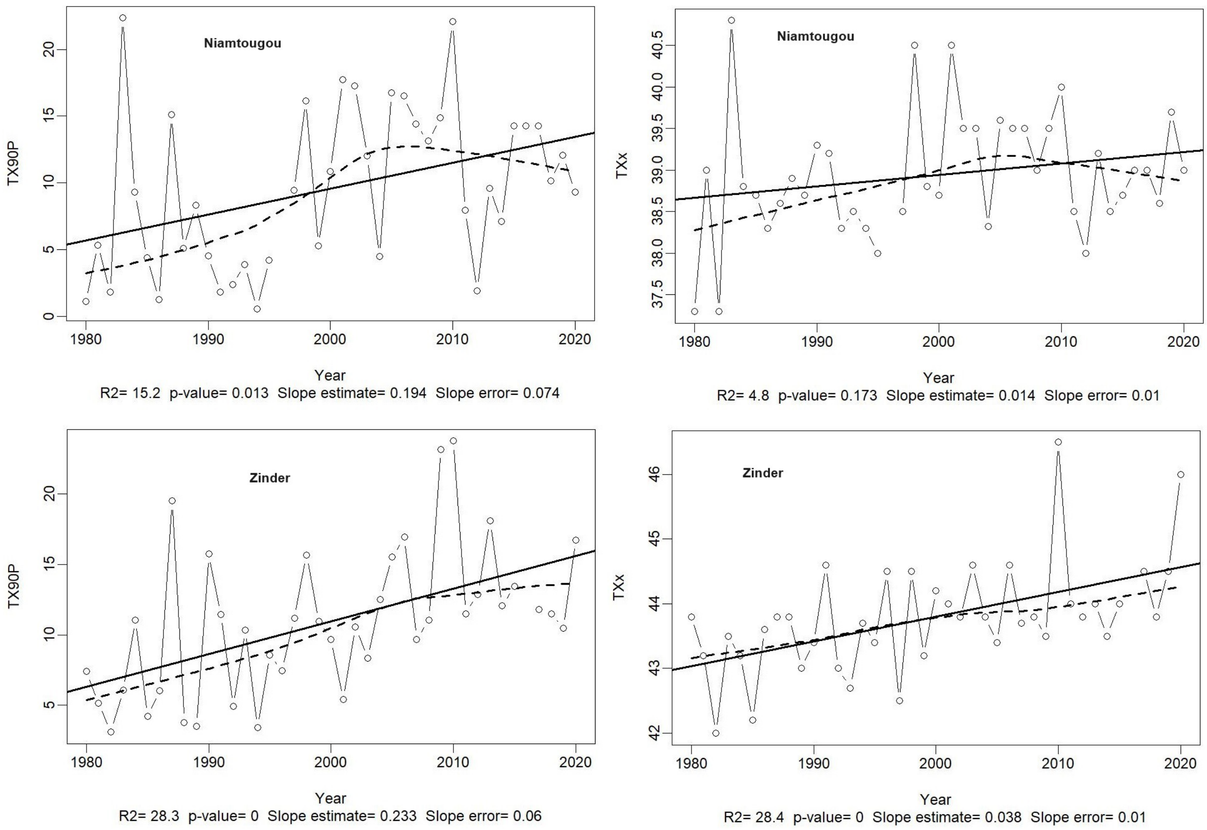

Figure 3. Trends of TX90p and TXx from 1980-2020. The solid line represents the estimated liner trend while the dot-dashed line represents the polynomial trend line.

4. Conclusion

This study analyzed the evolution of extreme precipitation and temperature indices in Niamtougou (Togo) and Zinder (Niger) from 1980 to 2020 based on daily rainfall and temperature time series data. The results showed an increase in all extreme rainfall indices in both Niamtougou and Zinder. As for the indices relating to extreme temperatures, only the frequency of cool days and the frequency of cool nights show a negative trend in these two cities. These observed changes in climate extreme indices could worsen in the context of ongoing climate change with negative socio-economic impacts in these two cities. Consequently, adaptation strategies to climate change, particularly heatwaves and floods, must be integrated into the municipal development plans of these localities. For instance, West African countries can improve their national meteorological and hydrological services as well as their early warning systems for extreme climate events.

Acknowledgments

The author would like to thank the Togolese national agency of meteorology and the directorate of national meteorology of Niger for providing the meteorological data. Also, we would like to thank CERViDA-DOUNEDON for the financial support.

Conflicts of Interest

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

References

Audu, M. O., Ejembi, E., & Igbawua, T. (2021). Assessment of Spatial Distribution and Temporal Trends of Precipitation and Its Extremes over Nigeria. *American Journal of Climate Change, 10,* 331-352. https://doi.org/10.4236/ajcc.2021.103016

Barry, A. A., Caesar, J., Klein Tank, A. M. G., Aguilar, E., McSweeney, C., Cyrille, A. M. et al. (2018). West Africa Climate Extremes and Climate Change Indices. *International Journal of Climatology, 38,* e921-e938. https://doi.org/10.1002/joc.5420

Bichet, A., Diedhiou, A., Hingray, B., Evin, G., Touré, N. E., Browne, K. N. A. et al. (2020). Assessing Uncertainties in the Regional Projections of Precipitation in Cordex-Africa. *Climatic Change, 162,* 583-601. https://doi.org/10.1007/s10584-020-02833-z

Blakime, T. -H., Komi, K., Adjonou, K., Hlovor, A. K. D., Gbafa, K. S., Oyedele, P. B., Polorigni, B., & Kokou, K. (2024). Derivation of a GIS-Based Flood Hazard Map in Peri-Urban Areas of Greater Lomé, Togo (West Africa). *Urban Science, 8,* 96. https://doi.org/10.3390/urbansci8030096

Cooper, P. J. M., Dimes, J., Rao, K. P. C., Shapiro, B., Shiferaw, B., & Twomlow, S. (2008). Coping Better with Current Climatic Variability in the Rain-Fed Farming Systems of Sub-Saharan Africa: An Essential First Step in Adapting to Future Climate Change? *Agriculture, Ecosystems & Environment, 126,* 24-35. https://doi.org/10.1016/j.agee.2008.01.007

Elagib, N. A., Zayed, I. S. A., Saad, S. A. G., Mahmood, M. I., Basheer, M., & Fink, A. H. (2021). Debilitating Floods in the Sahel Are Becoming Frequent. *Journal of Hydrology, 599,* Article 126362. https://doi.org/10.1016/j.jhydrol.2021.126362

Halissou, Y., Eric, A. A., Ezéchiel, O., & Eliézer, B. I. (2021). Extreme Temperature Trends in the Beninese Niger River Basin (Benin). *American Journal of Climate Change, 10,* 371-385. https://doi.org/10.4236/ajcc.2021.104018

IPCC (2013). Climate Change 2013. Scientific Elements. In *Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 127). Cambridge University Press.

IPCC (2021). Technical Summary. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* (pp. 33-144). Cambridge University Press.

Jiqin, H., Gelata, F. T., & Chaka Gemeda, S. (2023). Application of MK Trend and Test of Sen's Slope Estimator to Measure Impact of Climate Change on the Adoption of Conservation Agriculture in Ethiopia. *Journal of Water and Climate Change, 14,* 977-988. https://doi.org/10.2166/wcc.2023.508

Klassou, K. S., & Komi, K. (2021). Analysis of Extreme Rainfall in Oti River Basin (West Africa). *Journal of Water and Climate Change, 12,* 1997-2009. https://doi.org/10.2166/wcc.2021.154

Komi, K., Houedakor, Z. K., Adjalo, K. D., & Klassou, S. K. (2022). Evolution des indices de précipitations et de température extrêmes à Kara et Atakpamé au Togo de 1961 à 2018, *Revue de Géographie du Lardymes, 29,* 84-93.

Kumar, N., Panchal, C. C., Chandrawanshi, S. K., & Thanki, J. D. (2017). Analysis of Rainfall by Using Mann-Kendall Trend, Sen's Slope and Variability at Five Districts of South Gujarat, India. *Mausam, 68,* 205-222. https://doi.org/10.54302/mausam.v68i2.604

Ly, M., Traore, S. B., Alhassane, A., & Sarr, B. (2013). Evolution of Some Observed Climate Extremes in the West African Sahel. *Weather and Climate Extremes, 1,* 19-25. http://dx.doi.org/10.1016/j.wace.2013.07.005

Mann, H. B. (1945). Nonparametric Tests against Trend. *Econometrica, 13,* 245-259. https://doi.org/10.2307/1907187

Pinto, I., Odoulami, R. C., Lawal, K. A., Olaniyan, E., Ibrahim, W. A. et al. (2024). *Dangerous Humid Heat in Southern West Africa about 4°C Hotter Due to Climate Change*. https://doi.org/10.25561/110082

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

Touré Halimatou, A., Kalifa, T., & Kyei-Baffour, N. (2017). Assessment of Changing Trends of Daily Precipitation and Temperature Extremes in Bamako and Ségou in Mali from 1961-2014. *Weather and Climate Extremes, 18,* 8-16. https://doi.org/10.1016/j.wace.2017.09.002

Zhang, X., & Yang, F. (2004). *RClimDex (1.0), User Manual. Climate Research Branch, Environment Canada, Downsview, Ontario, Canada*. https://github.com/ECCC-CDAS/RClimDex

Zhang, X., Alexander, L., Hegerl, G. C., Jones, P., Tank, A. K., Peterson, T. C. et al. (2011). Indices for Monitoring Changes in Extremes Based on Daily Temperature and Precipitation Data. *WIREs Climate Change, 2,* 851-870. https://doi.org/10.1002/wcc.147