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Spatio-temporal variability of temperature in the Montagnes district (Western Côte d'Ivoire) from 1961 to 2020.

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Abstract

This study investigates the spatio-temporal dynamics of temperature in the Montagnes District, located in western Côte d'Ivoire, over the period 1961–2020. The analysis draws upon a combination of long-term meteorological observations from ORSTOM (1961–2000) and satellite-derived temperature data extending through 2020. A rigorous data preprocessing protocol was applied to correct systematic biases and address missing values, thereby ensuring the robustness and consistency of the time series.Temperature trends and structural shifts were assessed using a suite of statistical tests, including the distribution-free CUSUM method and Student's t-test for change-point detection, as well as the non-parametric Mann-Kendall test and simple linear regression for trend analysis. Results reveal a statistically significant warming trend in annual mean temperatures, estimated at +0.0011 °C per year, corresponding to an approximate 3% increase over the study period. The spatial distribution of thermal isohyets indicates pronounced heterogeneity across the district, with a consistent north–south gradient reflecting cooler northern and warmer southern zones.The intra-annual thermal amplitude, reflected in an average difference of 2.16 °C between maximum and minimum monthly temperatures, underscores notable thermal variability. Monthly analyses reveal a well-defined seasonal cycle, with temperature peaks in March and minima during the core rainy season (June–August). Notably, the most recent decade (2011–2020) exhibits an intensification of warming, particularly during March, April, and November, where recorded temperatures consistently exceed historical baselines. These findings highlight an accelerating regional warming pattern within the Montagnes District, likely attributable to broader global climate change processes. The observed trends call for the development of locally tailored adaptation strategies, particularly in the domains of agriculture and water resource management.

Keywords: Temperature Variability; Climate Change; Tropical Highlands; Warming Trends; Côte d'Ivoire

1. Introduction

In Côte d'Ivoire, climate parameters have been increasingly influenced by widespread deforestation, greenhouse gas emissions from industrial activities and vehicles, and atmospheric pollution involving N_2O, CH_4, and CO_2. Since the late 1960s, the country—alongside much of West and Central Africa—has witnessed a growing intensity in climate variability. This is particularly reflected in altered rainfall regimes and a consistent decline in annual precipitation. The onset of reduced rainfall in Côte d'Ivoire, mirroring trends observed across other Gulf of Guinea countries and the Sahel region, began in the late 1960s and intensified during the 1980s and 1990s, with only a marginal recovery observed in the early 2000s [1].

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Characterizing climatic variability in Côte d'Ivoire has been the focus of numerous studies employing a variety of analytical methods, including rainfall indices (e.g., Nicholson Index), statistical change-point detection (e.g., Pettitt test, Hubert segmentation), spatial tracking of isohyet migration, and linear trend analyses [2]. These investigations have consistently demonstrated the occurrence of rainfall discontinuities between 1966 and 2000, leading to an average precipitation deficit of approximately 21%, accompanied by a regional temperature increase ranging between +1°C and +1.6°c, over the 1960–2010 period.

The persistence of climate variability impacts highlights the challenges in capturing the full scope of the phenomenon, particularly in understanding its recent and ongoing evolution. This difficulty is accentuated by the fact that most prior studies examining climate variability in Côte d'Ivoire rarely extend beyond the year 2000, or 2005 at best. Thus, updating previous findings is essential for accurately assessing current environmental constraints and integrating climate considerations into national socio-economic development strategies [3].

The Montagnes District is particularly relevant in this regard due to its distinctive geomorphological features and its strategic economic role. Accordingly, it is imperative to investigate how temperature patterns have evolved in this region over recent decades. This study, therefore, focuses on: The spatio-temporal variability of temperature in the Montagnes District (Western Côte d'Ivoire) from 1961 to 2020.

A refined understanding of climatic parameter variability—particularly temperature—within the Montagnes District will enable better alignment of development projects with local realities and facilitate proactive adaptation to the potential impacts of ongoing climate change.

2. Material and methods

2.1. Study Area

The Montagnes District is located in western Côte d'Ivoire, between latitudes 5.500° and 8.200° North and longitudes 7.000° and 8.500° West. It comprises the regions of Guémon, Cavally, and Tonkpi, with key urban centers including Biankouma, Man, Danané, Bangolo, Duékoué, Guiglo, and Toulépleu (Figure 1). The district capital is the city of Man. Bordered by Guinea and Liberia, the district spans approximately 31050 km^2 and had an estimated population of 3027023 inhabitants according to the 2021 General Population and Housing Census [4].

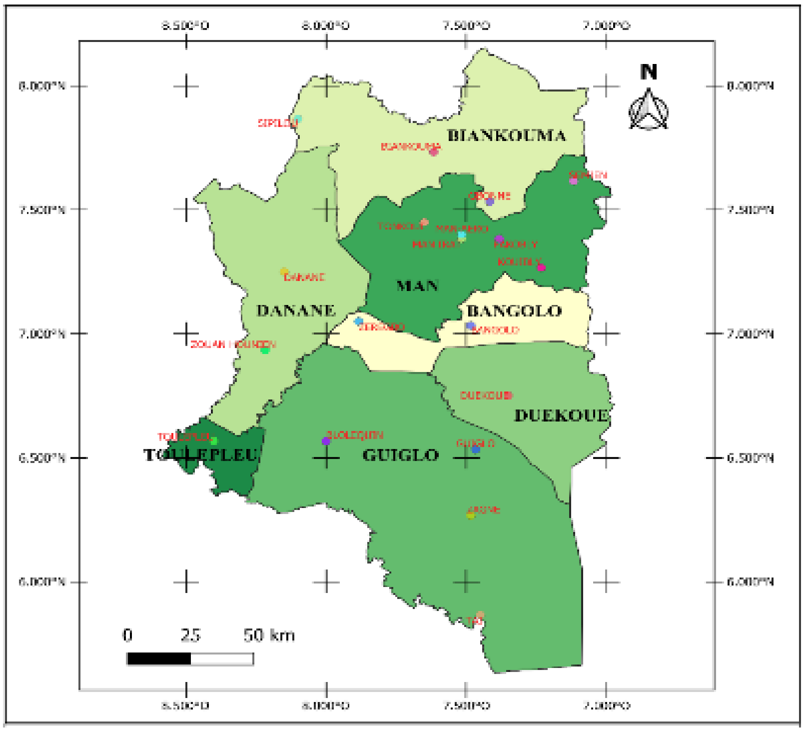

Figure 1 Map of the Montagnes district showing the regions and the spatial distribution of rainfall stations

2.2. Data Sources

2.2.1. Meteorological Data

The dataset includes monthly minimum and maximum temperature values, compiled from both physical weather stations (synoptic stations) and satellite-derived virtual stations. The virtual stations are georeferenced to the same coordinates as their corresponding physical stations.

Physical Station Data

The data from the physical stations come from the ORSTOM database. Physical stations with gaps and short time series had their missing data filled and, in some cases, their series extended using bias correction methods based on satellite data. Figure 1 shows the spatial distribution of the stations selected for the study

Satellite Data

The satellite temperature data are derived from the TerraClimate database, which provides monthly climate and climatic water balance data for global terrestrial surfaces from 1958 to 2021. All data have a monthly temporal resolution and a spatial resolution of approximately 4 km. The dataset covers the period 1958–2021 [5]. The data are available at http://www.climatologylab.org/terraclimate.html. For the purpose of this study, the time series from 1960 to 2020 was selected. The coordinates of the stations used correspond to those of the physical stations from the ORSTOM database.

2.2.2. Data Processing Tools

The processing and analysis of the data were carried out using several complementary soft-ware tools, enabling the manipulation of time series, the execution of statistical tests, and the cartographic representation of results. The Trend software (v1.0.2), available at www.toolkit.net.au/trend, was used to perform trend tests (Mann-Kendall and linear regression) as well as change-point detection tests (CUSUM without distribution and Student's t-test), due to its relevance for analyzing hydro-meteorological time series. For the processing of satellite data, preprogrammed Excel spreadsheets, including the Linear Scaling Bias Correction v1.0 module, were used to correct systematic biases. The production of maps of the study area—including the location of stations and the spatial distribution of precipitation and temperature isohyets—was carried out using the QGIS GIS software. In addition, RStudio was used for processing databases from ORSTOM, particularly for imputing missing data with the help of specialized packages such as VIM and VIMGUI. Finally, the KTRLine tool (version 1.0) was employed to apply the non-parametric Kendall-Theil robust regression method, which is particularly well-suited for identifying trends in time series with high variability or non-normal distributions [6]. Altogether, these tools ensured a rigorous and methodologically appropriate analysis of the complex rainfall datasets studied.

2.3. Methods

2.3.1. Satellite Bias Correction

From a spatial perspective, the resolution of satellite data is on the order of several tens of kilometers. However, these dimensions are too coarse to provide finely spatialized information. This gap between the need for high spatial resolution and what satellites can offer explains the efforts made toward spatial downscaling [7]. Satellite-based climate models often exhibit biases in climate simulation. In particular, precipitation is largely underestimated, and to a lesser extent, temperature as well. Therefore, before any use of these data, we applied bias corrections using the Delta approach. This method establishes correction factors by comparing the statistical properties of satellite data with those from ground-based stations. In the Delta approach, additive correction is preferred for temperature, while multiplicative correction is more suitable for variables such as precipitation, vapor pressure, solar radiation, etc. [8]. The Excel spreadsheet tool linear Scaling (version 1.0) was used to perform the bias correction [8].

2.3.2. Stationarity and Change-Point Detection

The VIM package [9] in the R software environment was used to impute missing values in the various time series from ground-based stations for the purposes of this study. The methods selected for detecting breakpoints and trends in the time series are based on the synthesis works of [10] and [11]. Hydrological time series are rarely symmetric, and the assumption of normality is not always satisfied. The non-parametric tests used to detect breaks in the series include the Mann-Kendall test, the distribution-free cumulative sum test (Free-CUSUM), and the student's t-test. Trend analysis was applied to precipitation series to assess the temporal distribution of the records (linearity, cyclic behavior of the phenomena) in the study basins. These parametric and non-parametric methods (linear regression, Mann-Kendall, etc.)

have also been cited by authors such as [12]. Among these methods, however, the Mann-Kendall test has proven to be particularly effective in numerous studies for characterizing trends in hydroclimatic time series [13].

2.3.3. Sen's Slope and Rate of Change

If a linear trend is present in the time series, the true slope can be estimated using a simple non-parametric test known as Sen's slope estimator. [14] developed a non-parametric procedure to estimate the trend slope from a sample of N data pairs :

$$T_i = \frac{X_j - X_k}{j-k} \qquad i= 1, 2, 3, \ldots N \qquad (1)$$

where Xj and Xk represent the data values at time steps "j" and "k" respectively, with "j" being greater than "k". The median of these "N" Ti values is called the Sen's slope estimator and is calculated using the following formulas :

$$\text{If N is even: } \beta = \frac{1}{2}\left(\frac{T_N}{2} + \frac{T_{N+2}}{2}\right)$$

$$\text{If N is odd: } \beta = \left(\frac{T_{N+1}}{2}\right) \ldots\ldots\ldots\ldots\ldots\ldots(2)$$

The sign reflects the direction of the data trend, while its value indicates the slope of the trend. To determine whether the median slope is statistically different from zero, a confidence interval should be obtained with a specific probability :

$$\%\Delta = \left(\frac{\beta * longeur\ de\ la\ periode}{Moyenne}\right) * 100 \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where Δ is the rate of change and β is the Sen's slope.

2.3.4. IDW Interpolation (Inverse Distance Weighting)

The Inverse Distance Weighting (IDW) method, which employs the inverse distance weighting technique, is a simple and effective interpolation approach based on the assumption that the values of variables at unsampled locations are similar to those of nearby observation points. This method assumes that each station exerts a local influence, which decreases with distance through the use of a power parameter [15]. The IDW method was employed to spatially interpolate annual rainfall totals (isohyets) and mean daily temperatures in the Mountain District.

2.3.5. Map Design with QGIS

In practice, geographic data come from different sources and have various acquisition methods. These data, originating from different media, are referred to as multisource. It is important to recall that a Geographic Information System (GIS) is a composite system; it brings together computer hardware, spatial analysis software, geographic and digital data to process and manage georeferenced data (WGS, UTM), transforming them into useful information for decision-making, generally presented in the form of maps [16].

The design of a Geographic Information System (GIS) is based on a rigorous methodology, structured around five fundamental steps that ensure the coherence and reliability of the spatial analysis process. The first phase consists of designing or generating the database, during which relevant geographic entities and attribute variables are defined according to the study objectives. This step constitutes the structural foundation of the system. It is followed by data acquisition and entry, involving the collection, digitization, and integration of spatial and thematic data into the GIS environment.

The third step, data management, allows organizing, structuring, and updating the various information layers to ensure their accessibility, traceability, and quality. Next comes the processing and analysis phase, during which data are exploited through geospatial operations (overlay, spatial queries, multi-criteria analyses, etc.) to produce relevant indicators and address specific issues.

Finally, the entire process culminates in the display and interpretation of results, generally in the form of thematic maps, graphical visualizations, or summary reports, aimed at facilitating decision-making, communicating scientific results, or guiding planning policies.

3. Results

3.1. Stationarity of Temperature Series in the Montagnes District

The non-parametric CUSUM test shows no breakpoints. However, the parametric t-Student test reveals breakpoints in all stations except for Bangolo, Semien, and Zeregbo, where the results agree with the CUSUM test. The findings differ for the two trend tests (Mann-Kendall and Linear Regression), which show an upward trend for almost all the stations studied (Table 1). Indeed, both the linear regression test and the Mann-Kendall test indicate an increasing trend at significance levels of α = 0.10 and α = 0.05.

Table 1 Break and Trend Tests of Temperature Series from Stations in the Montagnes District.

STATION	**Change-point test**				**Trend Test**			
	CUSUM		T-Student		Mann-Kendall		Rég. Linéaire	
	Vk	$Stat_{0,10}$	t	$Stat_{0,10}$	Z	$Stat_{0,10}$	t	$Stat_{0,10}$
Bangolo	350	384	-0.39	2.43	4.86	1.90	5.59	1.98
Biankouma	237	274	-3.97	2.10	4.57	1.91	5.70	2.03
Blolequin	287	322	-4.70	2.21	5.15	1.91	6.19	2.21
Danané	79	468	-6.84	2.14	5.96	1.84	6.82	2.04
Duékoué	203	244	-3.71	2.36	5.08	1.95	5.89	1.95
Fakobly	161	195	-5.21	2.47	4.81	1.81	5.52	2.01
Gbonné	295	334	-3.03	2.24	5.10	1.92	6.01	1.90
Guiglo	142	159	-7.09	2.35	5.65	1.90	6.39	1.99
Kouibly	93	115	-6.89	2.34	5.33	1.89	6.00	2.03
Man-Aéro	137	172	-5.16	2.52	5.18	1.87	5.85	1.98
Man-Irat	151	188	-5.33	2.29	4.94	1.85	5.65	2.00
Semien	324	352	-1.07	2.48	4.74	1.82	5.44	1.94
Sipilou	141	163	-7.12	2.06	5.87	1.85	6.88	2.02
Taï	143	149	-6.57	2.36	5.37	1.90	5.82	2.00
Tonkoui	113	121	-7.25	1.96	6.38	1.93	7.46	2.07
Toulepleu	344	378	-4.31	2.03	4.98	1.95	5.96	2.02
Zagné	245	273	-6.41	2.42	5.70	1.83	6.45	1.84
Zérégbo	388	416	-0.50	2.32	5.41	1.93	6.30	1.88
Zouan-Hounien	265	297	-4.82	2.10	5.83	1.94	6.91	1.92

3.2. Regional Magnitude of Trends: Sen's Slope

The analysis of the regional trend magnitudes shows that the slopes are positive but very low from one station to another (Table 2). The average temperature exhibited an increasing trend for the majority of stations in the Montagnes district. The magnitude and percentage changes of the trend obtained from the Mann-Kendall test for all stations are presented in Table 2. The annual mean temperature increased across all stations by 0.0011°C/year, with a percentage variation around 3% at significance levels of 5% and 10%.

Table 2 Analysis of Annual Temperature Trends and Percentage Change in the Montagnes District (1961–2020).

Stations	$Z_{0,10}$	B**	%Δ*
Bangolo	4.86	0.00116	3.28
Biankouma	4.57	0.00113	3.41
Blolequin	5.15	0.00115	3.21
Danané	5.96	0.00115	3.27
Duékoué	5.08	0.00118	3.26
Fakobly	4.81	0.00113	3.23
Gbonné	5.10	0.00112	3.27
Guiglo	5.65	0.00121	3.31
Kouibly	5.33	0.00113	3.22
Man-Aéro	5.18	0.00124	3.55
Man-Irat	4.94	0.00113	3.24
Semien	4.74	0.00111	3.14
Sipilou	5.87	0.00113	3.37
Taï	5.37	0.00114	3.11
Tonkoui	6.38	0.00113	3.50
Toulepleu	4.98	0.00111	3.10
Zagné	5.70	0.00118	3.26
Zérégbo	5.41	0.00115	3.24
Zouan-Hounien	5.83	0.00115	3.19

*%Δ percentage change and *β *Sen's slope*

3.3. Temperature Isohyets

Across all stations, lower average temperatures are observed in the North, while higher average temperatures are recorded in the South. The variation between the maximum and minimum average temperatures is 2.16°C. The lowest decadal annual mean temperatures are observed in the Biankoma and Siplou areas (24° to 24.54°C), at the far North of the district. The highest temperatures (26.7° to 27°C) are generally recorded in the far South at Taï, Zagne, Guiglo, and Duekoue during the first four decades (1961–2000), but also in the southwest sector of Blolequin and Zouan-Hounien for the decade 1981–1990 (Figure 2).

For the last two decades, the highest temperatures (26.7° to 27°C) are observed only in the Taï area, as well as in Guiglo during the last decade (2011–2020). The results of the isohyets for the spatial evolution of temperature over these six decades show a temperature variation of about 1°C. This observed decrease is approximately 1°C to 1.3°C depending on the stations, compared to previously observed decades (figure 3).

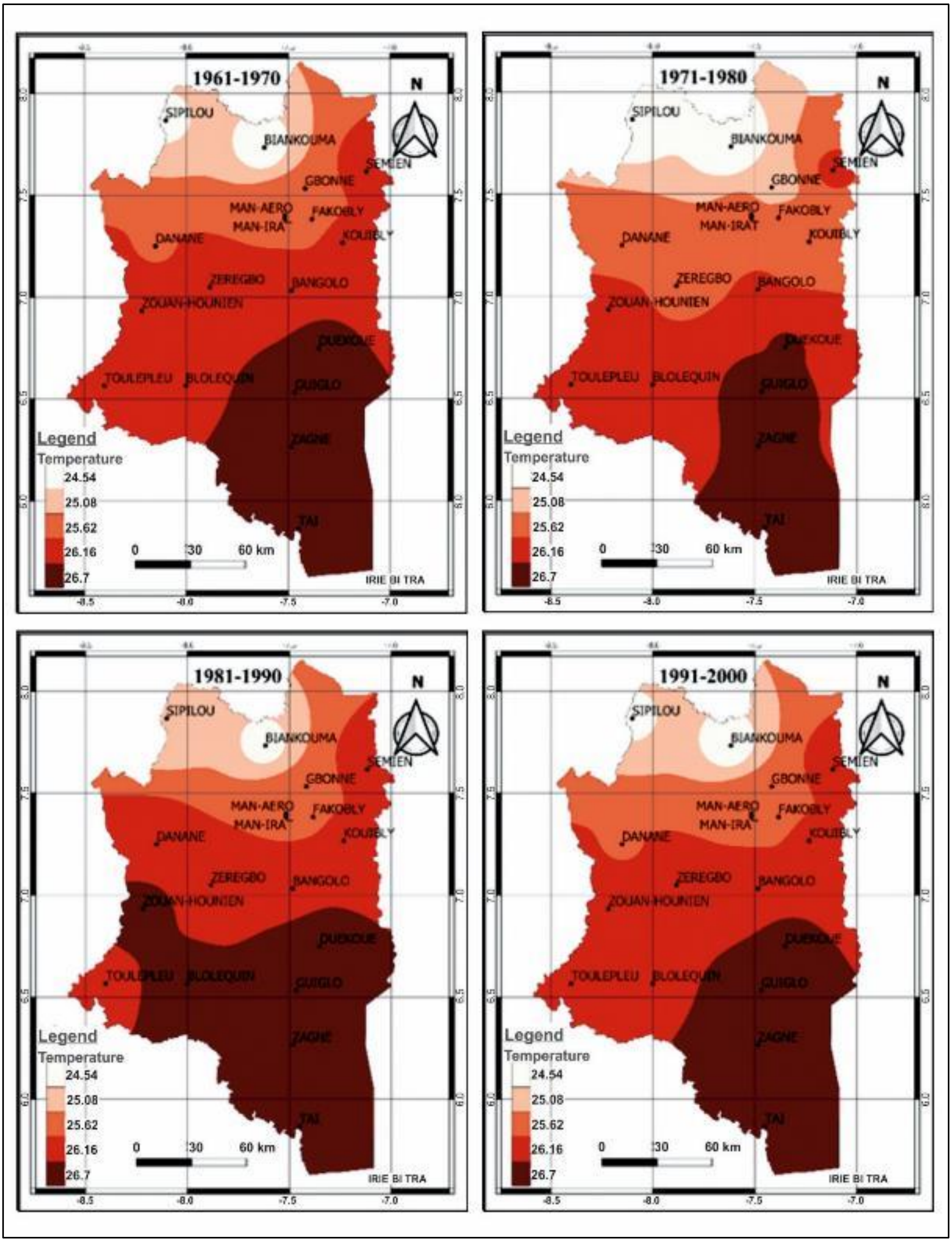

Figure 2 Decadal Temperature Isohyet Maps from 1961 to 2000, Covering Four (4) Decades

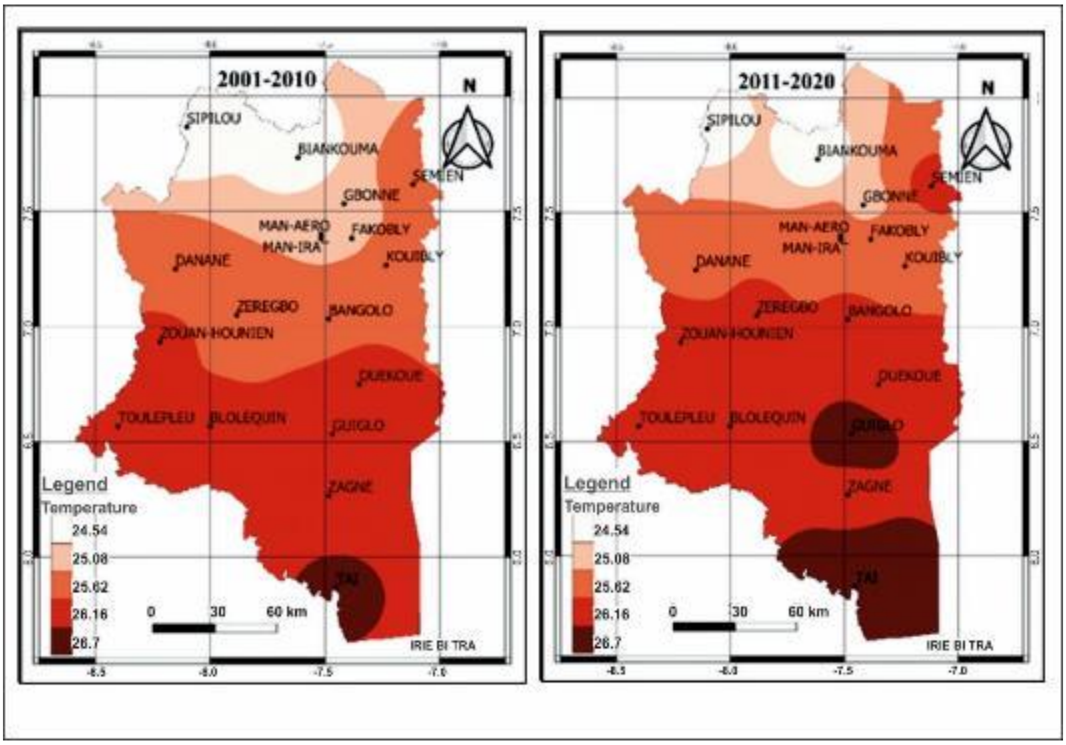

Figure 3 Decadal Temperature Isohyet Maps for 2001–2010 and 2011–2020

3.4. Evolution of Decadal Monthly Mean Temperatures in the Montagnes District

Figure 4 presents the monthly evolution of mean temperatures for each decade, from January to December. Regular seasonal variations are observed, characterized by a gradual increase in temperatures from January to March, peaking in March, followed by a marked decrease between May and August, and then a moderate rise towards the end of the year. During the period from January to December of the last decade (2011–2020), the mean temperature recorded in the Montagnes district was 25.9°C, representing an increase of +0.4°C compared to the 1961–1970 decade (25.5°C), and increases of +0.9°C, +0.6°C, +0.5°C, and +0.2°C compared to the other decades (1971–1980, 1981–1990, 1991–2000, and 2001–2010, respectively). Across all months, the monthly mean temperature values for the last decade (2011–2020) are higher than those of the other decades, except for February in the 1961–1970 decade, where a temperature of 28.8°C was observed, exceeding that of 2011–2020 by 1.8°C.

Overall, a warming trend is noticeable over the decades. Starting from the 1991–2000 decade, monthly temperatures generally remain higher than those recorded in previous decades, particularly in February, March, April, and November. The 2011–2020 period shows some of the highest temperatures, especially in March (approximately 2.8 °C), which could indicate regional climate warming.

The analysis also highlights a temperature anomaly in February 1961–1970, which exceeds other series and is likely related to a singular climatic event. However, this exception does not challenge the overall increasing temperature trend.

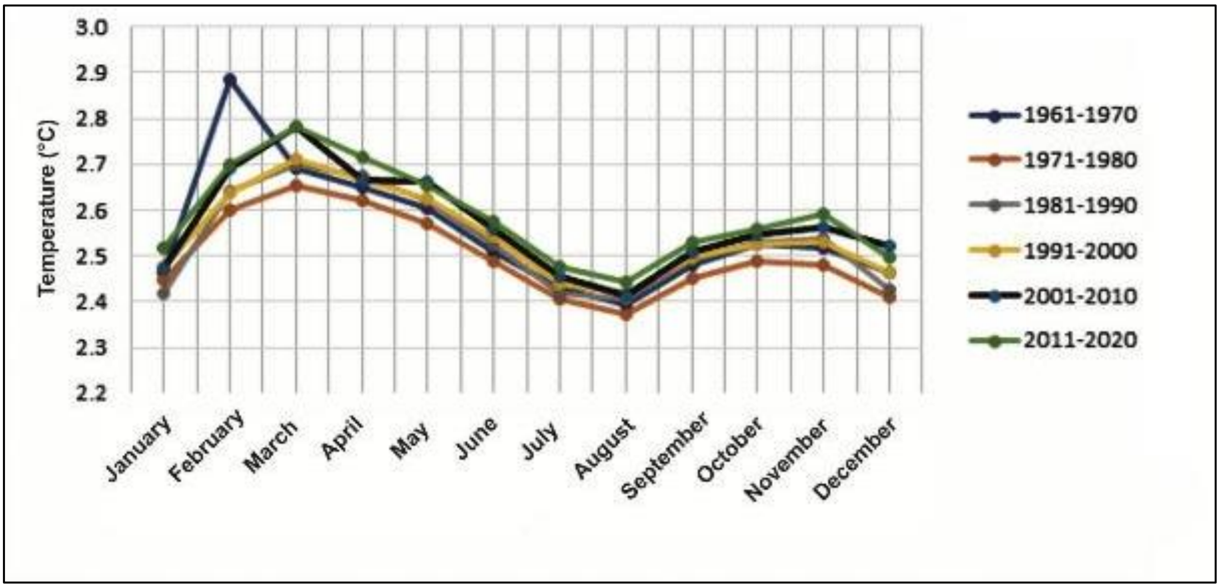

Figure 4 Evolution of Monthly Mean Temperatures in the Montagnes District

4. Discussion

The statistical analysis of temperature series using the non-parametric CUSUM test revealed no significant breaks across all observed stations. However, the parametric Student's t-test identified breakpoints in temperature series for the majority of stations, with the notable exceptions of Bangolo, Semien, and Zeregbo, where results were consistent with those of the CUSUM test. This discrepancy highlights the differing sensitivities of the statistical methods employed for detecting structural changes.

At the regional scale, the combined application of both tests indicates a notable climatic breakpoint period marked by a general trend of decreasing precipitation and rising temperatures. This transitional period is broadly situated between 1970 and 2000, consistent with observations by [3]. These findings confirm the climatic shift that began in previous decades within the Montagnes district and reinforce the hypothesis of a regional climate change simultaneously affecting thermal and rainfall regimes.

Trend analysis, conducted using linear regression and Mann-Kendall tests, shows an increase in temperatures across the district. Analysis of regional trend magnitudes using Sen's slope applied to mean temperatures indicates an upward trend for most stations in the Montagnes district. The annual mean temperature increased across all stations by 0.0011 °C/year, with a percentage change of 3%. In line with this, [3] report that temperature growth appears amplified across all climatic zones of Côte d'Ivoire, averaging 0.2°C per decade over 1961–2016 in the Man area (mountain climate). Furthermore, findings by Kouakou et al. (2012) for Côte d'Ivoire as a whole also show a temperature increase of approximately +1°C between 1960 and 2000. The mean temperature in the study area ranges from 23.7° to 28.8°C, with an annual average of 25.9°C. These results are consistent with those obtained by [17] in a similar study.

[17] also suggests that precipitation variability may be exacerbated by an estimated air temperature increase of about 0.007 °C, as observed in the Bongouanou region, aligning with a temperature rise trend between the hemispheres on the order of 0.08 °C per decade, leading to a disruption of the Intertropical Convergence Zone (ITCZ) migration mechanism, which governs West African climate ([17], [18], [19]). The causes of this temperature increase are likely linked to deforestation of forested areas. According to [20] (1998), the diversity and variability of ecosystems, as well as the quantity and quality of available forest resources—which represent significant potential for the well-being of current and future generations—are diminishing daily in Côte d'Ivoire. Moreover, it cannot be excluded that rising temperatures and decreasing rainfall are also locally associated with the regression of dense leafy forests (effects related to albedo changes and reduced evapotranspiration).

5. Conclusion

This study confirms that, like other countries in tropical zones, Côte d'Ivoire is exposed to the effects of climate change. The temperature analysis in the Montagne's district, located in the west of the country, confirms this dynamic through the assessment of thermal variability over the period 1961–2020. The results reveal a general upward trend in temperatures, with significant breaks detected in certain localities. The application of the Mann-Kendall test to monthly mean temperatures indicates a statistically significant increase estimated at 0.0011 °C/year, corresponding to a rise of approximately 3% over the study period. Furthermore, the analysis of thermal isohyets highlights a heterogeneous spatial distribution of temperatures, with a marked thermal gradient from north to south of the district. These findings emphasize the need to adapt agricultural systems to new climatic conditions by developing planned adaptation strategies. Such approaches would strengthen the resilience of local farming operations, which largely depend on rainfed crops, against the increasing risks induced by climatic variability.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclsoed.

References

[1] Kouassi, A. M., Kouamé, K. F., Koffi, Y. B., Djè, K. B., Paturel, J. E., & Oulare, S. (2010). Analysis of climate variability and its influence on seasonal rainfall patterns in West Africa: Case of the N'Zi (Bandama) basin in Côte d'Ivoire. OpenEdition Journals, 138 ; 10400–23388.

[2] Kouassi, A. M., Kouao, J.-M., & Kouakou, K. E. (2022). Intra-annual characterization of climate variability in Côte d'Ivoire. Bulletin de l'Association de Géographes Français, 99(2), 289–306.

[3] Kouao, J.-M., Tagnon, B., Koffi, B., Kouassi, A. M., Kouassi, K. A., & Gone, D. L. (2024). Climate variability and recent interannual climate trends in West Africa: The case of Côte d'Ivoire. European Scientific Journal (ESJ), 34, 235. Retrieved from https://eujournal.org/index.php/esj/article/view/18651.

[4] INS (2021). General Population and Housing Census RGPH-2021, Global Results, 37 p.

[5] Abatzoglou, J. T., Dobrowski, S. Z., Parks, S. A., & Hegewisch, K. C. (2018). Terraclimate, a high-resolution global dataset of monthly climate and climatic water balance from 1958–2015. Scientific Data. http://www.climatologylab.org/terraclimate.html. Accessed April 5, 2021.

[6] Helsel, D. R., & Hirsch, R. M. (2002). Statistical Methods in Water Resources – Hydrologic Analysis and Interpretation: Techniques of Water Resources Investigations of the U.S. Geological Survey, Chapter A3, Book 4, pp. 266–274.

[7] Wilby, R. L., Charles, S. P., Zorita, E., Timbal, B., Whetton, P., & Mearns, L. O. (2004). Guidelines for the use of climate scenarios developed from statistical downscaling methods. Published online as supporting material to the Intergovernmental Panel on Climate Change, 27 p.

[8] Shrestha, S., Shrestha, M., & Babel, M. S. (2015). Modeling the potential impacts of climate change on the hydrology of the Indrawati River Basin in Nepal. Environmental Earth Sciences.

[9] Templ, M., Alfons, A., & Filzmoser, P. (2012). Exploring incomplete data using visualization tools. Journal of Advances in Data Analysis and Classification, Online First. DOI : 10.1007/s11634-011-0102-y.

[10] Lemaître, F. (2002). Review of trend and change-point detection tests suitable for stationarity analysis of flood regimes in France. Final study report, TPE, CEMAGREF, 94 p.

[11] Krishna, U. (2012). Studies in low and flood flow estimation for Irish river catchments. PhD thesis, National University of Ireland, Galway, 312 p.

[12] Kundzewicz, Z. W., & Robson, A. J. (2004). Change detection in hydrological records : a review of the methodology. Hydrological Sciences Journal, 49(1), 7–19.

[13] De Lima, M. I. P., Carvalho, S. C. P., & De Lima, J. L. M. P. (2010). Investigating annual and monthly trends in precipitation structure : an overview across Portugal. Natural Hazards and Earth System Sciences, 10(11), 2429–2440.

[14] Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. Journal of the American Statistical Association, 63(324), 1379–1389.

[15] Pingale, S. M., Khare, D., Jat, M. K., & Adamowski, J. (2014). Spatial and temporal trends of mean and extreme rainfall and temperature for the 33 urban centers of the arid and semi-arid state of Rajasthan, India. Atmospheric Research, 138, 73–90.

[16] Savané, I. (1997). Contribution to the geological and hydrogeological study of discontinuous aquifers in the crystalline basement of Odienné, northwestern Côte d'Ivoire. Contribution of remote sensing and a spatially referenced hydrogeological information system. PhD thesis in Natural Sciences, Université d'Abidjan, Côte d'Ivoire, 386 p.

[17] Adiaffi, B. (2008). Contribution of isotopic geochemistry, hydrochemistry, and remote sensing to the understanding of aquifers in the contact zone between the basement and the sedimentary basin in southeastern Côte d'Ivoire. PhD thesis, Université Paris Sud, Paris, France, 230 p.

[18] IPCC (2007). Climate Change : Synthesis Report on Climate Evolution, Geneva (Switzerland), 2000 p.

[19] Péné, B. C., & Assa, A. D. (2003). Interannual variations of rainfall and water supply for sugarcane in Côte d'Ivoire. Journal de Sécheresse, 14, 43–52.

[20] Aké-Assi, L. (1998). Impact of logging and agricultural development on the conservation of biological diversity in Côte d'Ivoire. Le Flamboyant, 48 : 85–87.