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TREND AND ANOMALY OF TEMPERATURE SERIES IN WEST AFRICAN COASTAL URBAN AREAS: THE CASE OF ABIDJAN, CÔTE D'IVOIRE (1985-2024)

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ABSTRACT

Climate change is accompanied by a growing intensification of temperatures at the local scale, as observed in several cities of the sub-region, yet their evolution and trends remain insufficiently quantified. This study aims to examine the trends and anomalies of temperatures in the city of Abidjan over the period 1985-2024. Daily maximum (TX), minimum (TN), and mean (TM) temperature data, provided by SODEXAM, were analyzed using the Mann-Kendall trend test combined with Sen's slope, as well as an anomaly index calculated relative to the 1985-2024 climatological normal. The results reveal a significant upward trend for both TN and TM over the entire period, with a marked intensification of nocturnal warming ($R^2 = 0.4096$). Anomaly analysis shows that 2001, 2002, and 2003 were the coolest years recorded (down to $-3.30\text{ }^{\circ}\text{C}$), while 2008 and 2010 were the warmest ($+1.3\text{ }^{\circ}\text{C}$) over the entire study period. At the monthly scale, February to April consistently concentrate the highest temperatures throughout the study period. Overall, the results reveal an upward thermal trend over the past two decades (since 2005), associated with an increase in minimum and mean temperatures in Abidjan. These results provide a climatological baseline for future research on the specific role of nocturnal warming in aggravating health risk in West African coastal urban settings.

Keywords: High Temperature, Thermal Trend, Nocturnal Warming, Coastal Urban Areas, Abidjan, Côte d'Ivoire.

1 INTRODUCTION

In the current era of global warming, understanding the dynamics of extreme temperatures is essential, as they constitute one of the aspects of climate change to which ecosystems and societies are most sensitive [1,2]. In urban areas, rising temperatures have notable repercussions on socioeconomic conditions, energy, water consumption, and human health [3,4].

According to the IPCC, global mean surface temperature increased by 0.85 °C between 1880 and 2012, mainly due to rising greenhouse gas concentrations [5]. Furthermore, an additional warming of 1.40 to 5.80 °C is expected by the end of the 21st century, likely to further increase the frequency and intensity of thermal extremes [6]. This trend affects all regions of the world, including tropical Africa [5]. West Africa, including Côte d'Ivoire, is part of this context, with statistically significant temperature increases already reported across most of Ivorian territory [1,7,8]. Numerous studies have also documented the intensification of thermal extremes in West Africa, mainly in the Sahelian context [9–11] or at the regional scale [12–14]. These thermal changes, combined with the increasing occurrence of extreme weather events (floods, severe droughts), are already affecting Côte d'Ivoire and are expected to intensify, exacerbating already unfavorable development conditions [15]. The country, a large part of whose territory lies along the densely populated Guinean coast, appears particularly vulnerable to these changes [16–18], its economy relying heavily on agriculture and climate-sensitive natural resources, the growth cycle of which is directly affected by rapid temperature changes and shifts in season length [19].

The present study therefore aims to examine the trends and anomalies in the maximum (TX), minimum (TN), and mean (TM) temperature series of the city of Abidjan over the period 1985-2024, in order to provide a climatological baseline for understanding local thermal dynamics and for the future assessment of their health repercussions on coastal urban populations.

2 MATERIALS

2.1 Description of the Study Area

Abidjan is the economic capital of Côte d'Ivoire. The city lies in the south, between latitudes 5°15'N and 5°26'N and longitudes 3°54'W and 4°05'W (Figure 1). It is the largest and most populous city in the country, with 5,616,633 inhabitants. This represents about 20% of the national population. It is also the most populous city in French-speaking West Africa [20]. Abidjan is divided into two areas: "North Abidjan" and "South Abidjan." The *Ebrié* Lagoon separates them. The city has a sub-equatorial (*Attiéen*) climate. Its weather follows a bimodal pattern made of two rainy seasons and two dry seasons [21]. Throughout the year, the rainy seasons are typically hot and cloudy, while the dry seasons are very hot and partly cloudy.

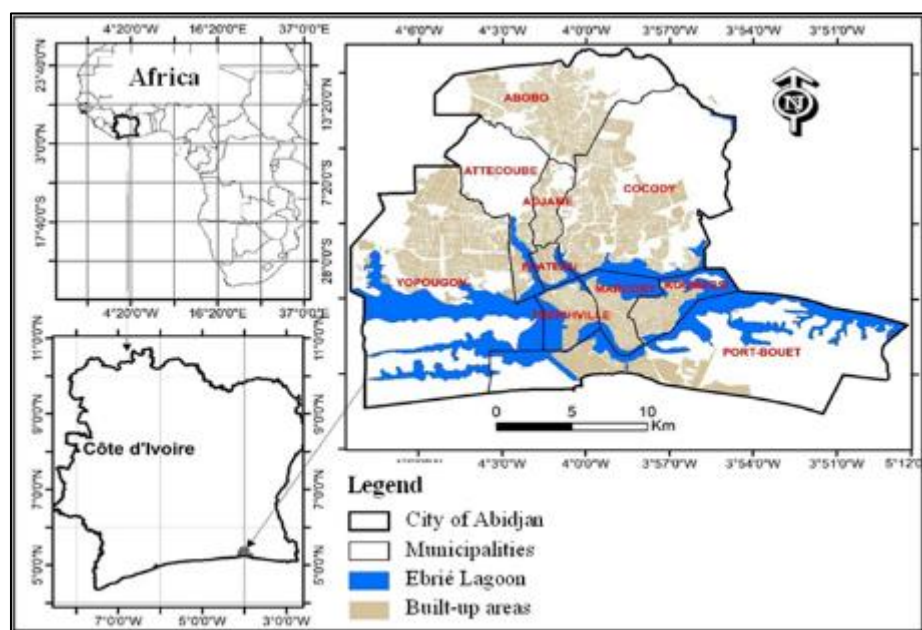


Figure 1: Presentation of the city of Abidjan.

2.2 Data Collection

Historical meteorological data used in this study were obtained from the Abidjan Air-port weather station and provided by the “Société d’Exploitation et de Développement Aéroportuaire, Aéronautique et Météorologique (SODEXAM)”. The dataset includes daily maximum (TX) and minimum (TN) temperatures spanning the period from 1985 to 2024 (40 years).

3 METHODS

3.1 Analysis of Intra- and Interannual Temperature Variation

The analysis was conducted using a descriptive approach and consisted of a graphical representation of the interannual and monthly fluctuations of the temperature variables. For this purpose, mean values were determined for each parameter. This average state was obtained through statistical calculation. In this study, the monthly, annual, and interannual mean of maximum (TX), minimum (TN), and mean (TM) temperatures over the period 1985-2024 was determined. This made it possible to understand the seasonal and annual variations in temperature in the city of Abidjan.

3.2 Trend Analysis

3.2.1 Statistical Tests for Trend Analysis

To determine the significance of the observed trends and calculate their magnitude over different time steps, the Mann-Kendall and Sen tests were applied to the daily TX, TN, and TM series from 1985-2024.

3.2.1.1 Mann-Kendall test

The Mann-Kendall test [22,23] is commonly used to detect monotonic trends in environmental, climatic, or hydrological data series [24]. One of its advantages is that it does not require the data to follow a normal distribution. It is also characterized by low sensitivity to abrupt breaks resulting from non-homogeneous time series [25]. Its null hypothesis (H_0) states that the variables follow a random distribution and that there is no clearly defined trend. Let $(x_i, \dots, x_n)$ be a sample of independent values drawn from a random variable X , whose stationarity is to be assessed; the Mann-Kendall statistic is defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^n \text{sign}(x_i - x_j) \quad (1)$$

where x_i and x_j are the sequential values of the data, and n is the length of the dataset.

The presence of a statistically significant trend is assessed using the Z value.

$$Z = \begin{cases} \frac{S-1}{\sqrt{\text{var}(S)}}, & S > 0 \\ 0, & S = 0 \\ \frac{S+1}{\sqrt{\text{var}(S)}}, & S < 0 \end{cases} \quad (2)$$

In the presence of tied values within the series, the variance of S can be defined as follows:

$$\text{Var}(S) = n(n-1)(2n+5) - \sum_{i=1}^n t_i i(i-1)/18 \quad (3)$$

where t_i denotes the number of ties involving k values.

A positive (or negative) value of Z indicates an upward (or downward) trend, and its significance is compared against the critical value, or significance threshold, of the test. In this analysis, the significance level is set at 5% and 1%.

3.2.1.2 Sen's Slope

Sen's slope [26], or the Theil-Sen estimator, is an extension of Theil's test [27]; it allows for the estimation of both the magnitude of the linear trend and the confidence levels [24,28]. It is considered to be a test that is significantly less sensitive to missing data and outliers, making it a more robust method than the least squares estimator.

It is calculated as the median of all slopes obtained by considering every possible pair of points in the time series. For a time series (x_i, t_i) with $i = 1, \dots, n$, the set of slopes between all possible pairs of points ($i < j$) is calculated as:

$$Q_{ij} = (x_j - x_i) / (t_j - t_i), \text{ for all } i < j \quad (4)$$

Sen's estimator (β) corresponds to the median of this set of $N = n(n-1)/2$ slopes, previously sorted in ascending order:

$$\beta = \begin{cases} Q_{\frac{(N+1)}{2}} & \text{if } N \text{ is odd} \\ \frac{1}{2} \left(Q_{\frac{N}{2}} + Q_{\frac{(N+2)}{2}} \right) & \text{if } N \text{ is even} \end{cases} \quad (5)$$

where Q_{ij} are previously sorted in ascending order, and β represents the median rate of change of the variable studied per unit of time ($^{\circ}\text{C}/\text{year}$).

To perform the trend tests, the Mann-Kendall function from the Kendall package [29] and the Sen's slope function from the R trend package [24] were used.

3.2.2 Calculation of Anomalies (Thermal Trends)

The anomaly index was used to highlight the temporal evolution of meteorological indices independently of their absolute level, based on daily temperature data (TX, TN, and TM) over the period 1985-2024 for each variable in this study. In accordance with the method of [30], the anomaly calculation is based on the long-term historical mean derived from the ensemble mean, in order to determine the deviation between an observed temperature and a reference temperature (statistical mean over a standard climatological period, 1985-2024). This transformation enables a standardized graphical representation, facilitating the preliminary visual detection of behavioral changes in the data series [4,9,31]. The anomaly calculation is based on the following standardized (z-score) index formula:

$$Z = \frac{x_i - \bar{X}}{\sigma} \quad (6)$$

where X_i : represents the observed annual value, $\bar{X}$: the reference mean over the period 1985-2024, and σ : the standard deviation of the data series of the study variable.

4 RESULTS

4.1 Intra-Annual Temperature Evolution from 1985-2024

Overall, the analysis of the average monthly temperature evolution shows that July, August, and September record the lowest values (ranging between 22.56°C and 28.33°C), whereas February, March, and April display the highest values of the year (ranging between 25.31°C and 31.78°C) (Figure 2). This analysis reveals seasonal fluctuations between 1985 and 2024. Maximum temperature values range between 28°C and 31.78°C , mean temperature values range between 25.85°C and 28.66°C , and minimum temperature values range between 23.50°C and 25.55°C .

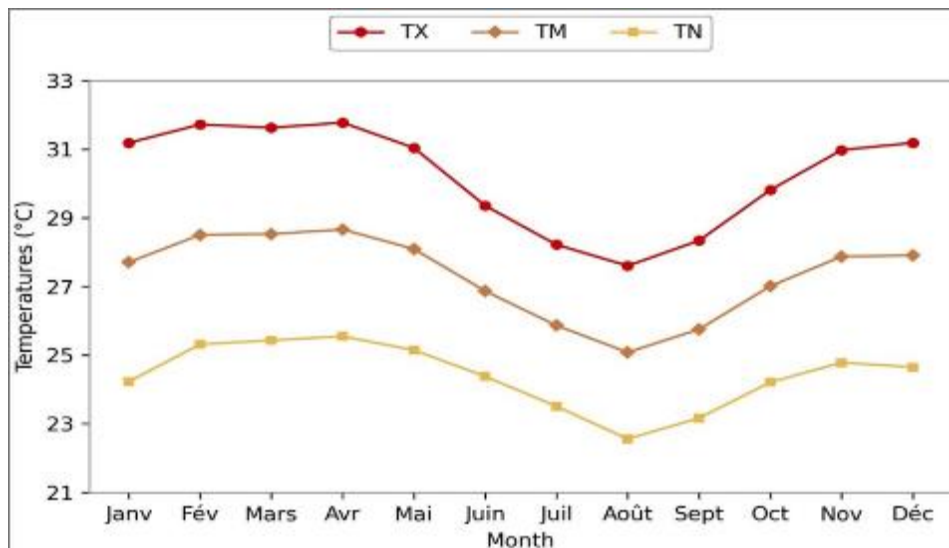


Figure 2: Average Intra-Annual Temperature Variations in Abidjan, 1985-2024

4.2 Interannual Temperature Evolution from 1985-2024

Figure 3 presents the annual evolution of temperatures from 1985 to 2024. In the city of Abidjan, a substantial interannual variability is observed in minimum (TN), mean (TM), and maximum (TX) temperatures, marked by a significant decline between 2001 and 2003. The overall analysis of temperatures shows a marked evolution in mean and maximum temperatures, ranging between 24.94 °C and 28.50 °C, and between 26.80 °C and 31.70 °C, respectively. Minimum temperature ranges between 23.08 °C and 25.34 °C.

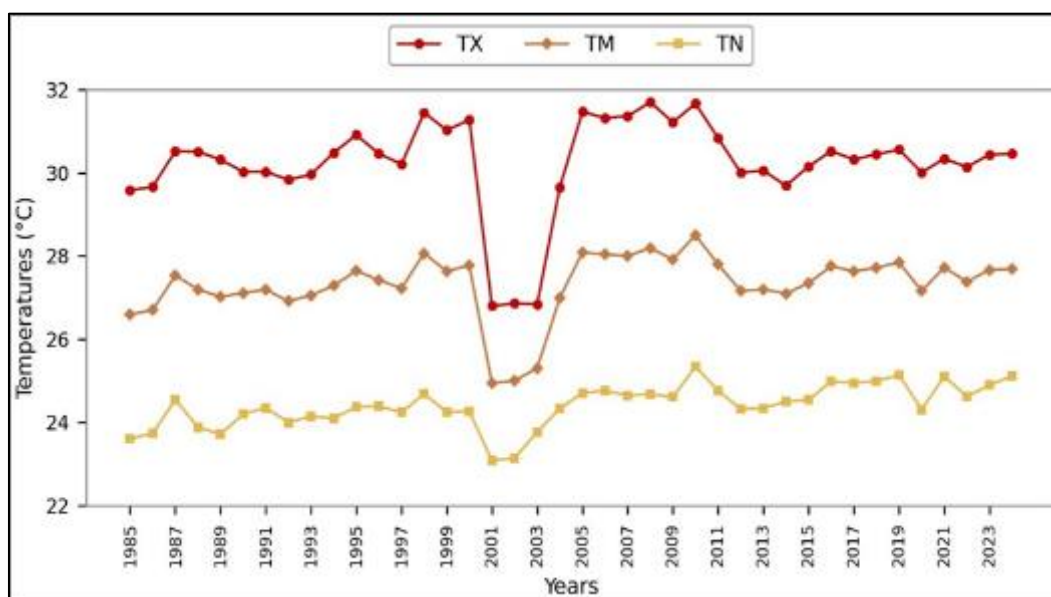


Figure 3: Average Annual Temperature Variation in the City of Abidjan, 1985–2024

4.3 Trend Analysis of Temperature Series from 1985-2024

The analysis of temperature evolution in Abidjan shows an overall upward trend, highly significant, for minimum (TN) and mean (TM) temperatures over the period 1985-2024 (Table 1). The evolution of annual TN shows a highly significant upward trend, with an average temperature increase of 0.030 °C per year. As for the evolution of TM, it shows an overall significant upward trend, with an increase of 0.018 °C per year. Furthermore, the evolution of annual TX shows an upward, but non-significant, trend, with a slight increase of approximately 0.009 °C per year.

Table 1: Climatic trends in mean annual temperatures (TX, TN, and TM) by sub-period before and after the breakpoints detected in Abidjan (1985–2024)

Significance levels: **p < 0,05; ***p < 0,01; NS = not significant							
Variables	Break period	n	MK Z	MK p-value	MK Significance	Conclusion (Trend)	Sen's slope (°C/year)
TX	Overall (1985-2024)	40	0.944	0.3453	NS	Non-significant increase	0.00914
TN	Overall (1985-2024)	40	4.742	0	***	Significant increase	0.0304
TM	Overall (1985-2024)	40	2.388	0.0169	**	Significant increase	0.01777

4.4 Annual Thermal Trends (Anomalies) from 1985-2024

The analysis of temperature anomalies relative to the reference mean values (30.23 °C for TX, 24.40 °C for TN, and 27.31 °C for TM) over the period 1985-2024 highlights two (2) major periods (1985-2004 and 2005-2024) (Figure 4).

The analysis of these anomalies (TX, TM, and TN) over the period 1985-2004 reveals an overall downward trend (cooler conditions), with a few warmer years (1987, 1998, and 2000). This period identifies 1998 as the warmest year, with an anomaly of 1.21 °C for TX and 0.75 °C for TM. The marked decline observed during 2001, 2002, and 2003 corresponds to a particularly cool period, with anomalies reaching as low as -3.43 °C for TX, -2.37 °C for TM, and -1.33 °C for TN. Over the period 2005-2024, overall positive anomalies are observed, reflecting a warming trend, with 2008 and 2010 standing out as the warmest years of the series. In 2008, anomaly peaks reached 1.47 °C and 0.88 °C for TX and TM,

respectively, whereas in 2010, they rose to 1.44 °C, 1.2 °C, and 0.94 °C for TX, TM, and TN, respectively. Furthermore, since 2005, the past two decades have been marked by an overall increase in temperatures, particularly significant for minimum temperature, with a correlation coefficient R of 0.64 ($R^2 = 0.4096$).

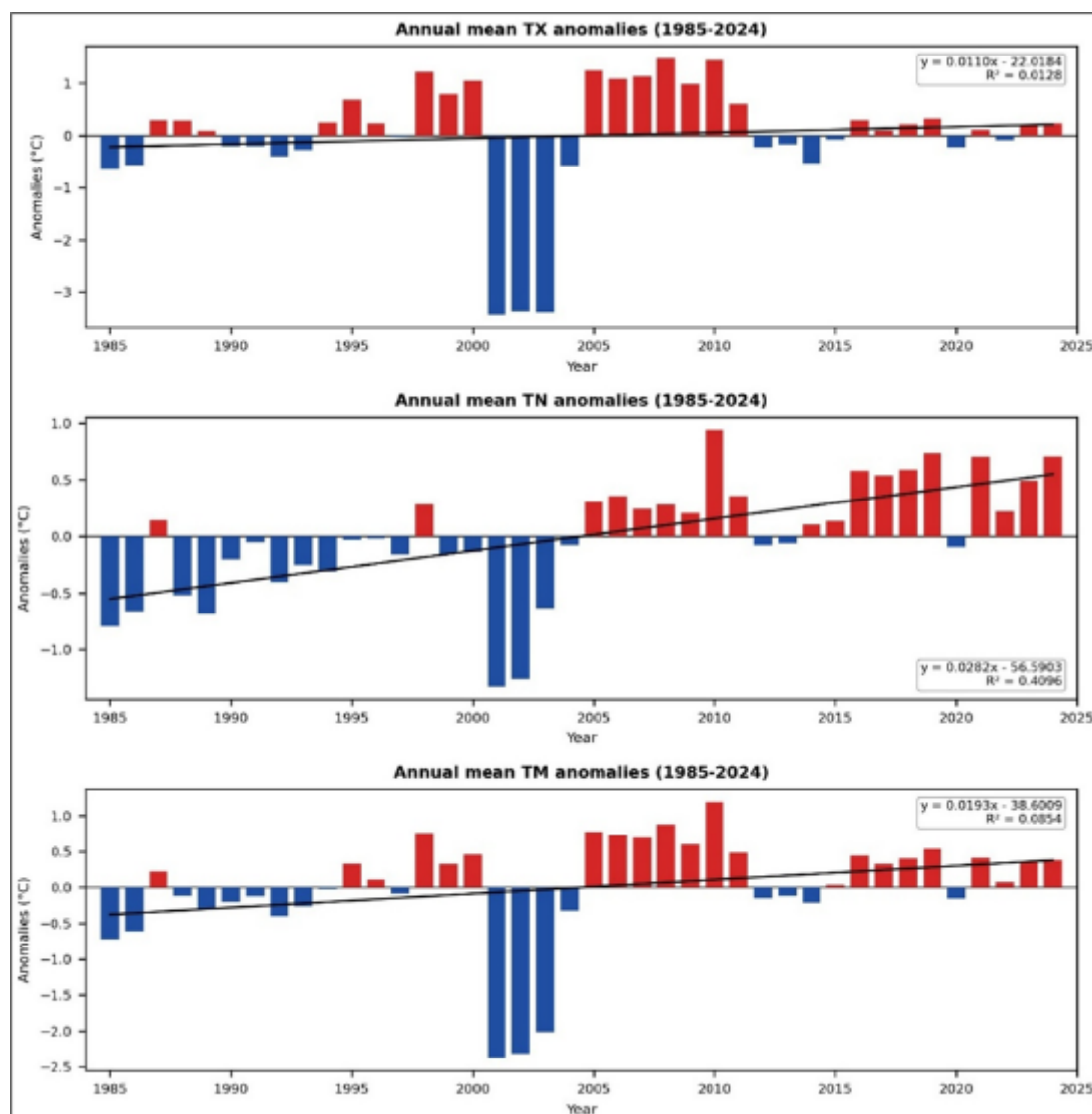


Figure 4: Trends in minimum, average, and maximum temperature anomalies in Abidjan from 1985 to 2024

5 DISCUSSION

The results reveal marked seasonal fluctuations in the temperature series in Abidjan over the period 1985-2024. The highest temperatures are concentrated in the period from January to May and from November to December, corresponding to the long dry season and the onset of the long rainy season. The months of February, March, and April systematically stand out as the most critical, concentrating the maximum values (ranging between 25.3 °C and 33.06 °C), while July, August, and September record the lowest values (ranging between 22.08 °C and 28.65 °C). These results could be explained by the strong insolation and the seasonal atmospheric transition specific to this period of the year, which favor the advection of hot, humid air and heat accumulation, making these months particularly conducive to thermal extremes. This seasonality is consistent with the findings of [32] and [33], who also observed an intensification of thermal extremes during these seasonal transition phases in Côte d'Ivoire, as well as those of [14] and [12], who show that most extremely hot episodes in West Africa occur during the dry season or at the onset of the rainy season.

At the interannual level, the results show that negative anomalies dominated before 2005, with 2001, 2002, and 2003 standing out as the coolest years of the entire study period, with anomalies reaching as low as -3.30 °C, while 1988 stands out as the warmest year of this same sub-period. After 2005, warm years intensified, culminating in 2008 and 2010 with anomalies exceeding 1.3 °C, years identified as the warmest of the entire series studied. This warming trend since 2005 suggests the establishment of a new local climatic norm, which could be linked to regional and global climatic disruptions associated with the La Niña and El Niño phenomena: the marked La Niña episodes (1999-2001, 2007-2009,

and 2010-2012) caused cooling in several tropical areas, while the El Niño episodes of 2002-2003 and 2009-2010 disrupted rainfall patterns and contributed to a rise in temperatures along the Guinean coast. The El Niño phenomenon indeed results from a weakening of the trade winds, which disrupts ocean-atmosphere circulation in the equatorial Pacific, leading to abnormal warming of sea surface temperatures and generating climatic repercussions on a global scale [34–36]. This thermal evolution also appears to result from global climate warming [1,2] and from sea surface temperature anomalies in the tropical Atlantic [35,37]. These results fit within a coherent regional context: in the Ivorian context, the work of [8] confirms, over the period 1960-2010, a temperature increase of between +1 and +1.6 °C, while the [1] establishes an average warming of Côte d'Ivoire of 0.6 °C since the 1960s, with 2010 identified as the most extreme year (anomaly of +1.3 °C) a finding also corroborated by the work of [9] in the Sahelian West Africa and of [4] in Senegal.

Furthermore, the results show a significant upward trend for TN and TM over the entire study period (+0.030 °C and +0.018 °C per year, respectively), whereas TX shows no significant trend. This highly significant increase in TN, the highest of the entire analysis ($R^2 = 0.4096$), confirms a progressive and sustained intensification of nocturnal warming, which could be explained by the rapid and unplanned urbanization of Abidjan since the 2000s: the increasing sealing of surfaces, along with the lack of green spaces and ventilation, indeed accentuate the urban heat island effect, a phenomenon whereby built surfaces store solar heat during the day and release it slowly at night, thereby slowing nocturnal cooling. This evolution of TN is consistent with several studies documenting an intensification of nighttime temperatures in sub-Saharan West Africa within the context of contemporary climate warming [4,9–11,38]. This predominance of nocturnal warming over daytime warming also constitutes a particularly worrying signal from a health perspective. Several recent epidemiological studies demonstrate that the absence of nocturnal cooling, reflected by elevated TN, constitutes one of the main factors of excess mortality during extreme heat episodes, as it deprives the body of any opportunity for recovery from the thermal stress accumulated during the day [39–41].

6 CONCLUSION

The results reveal a significant upward trend, observed for TN (+0.030 °C/year) and TM (+0.018 °C/year) over the entire period 1985-2024, with an intensification of nocturnal warming (TN) from 2005 onwards ($R = 0.64$; $R^2 = 0.4096$). Furthermore, the results show that 2001, 2002, and 2003 are the coolest years recorded (down to -3.30 °C), while 2008 and 2010 are the warmest (+1.3 °C) over the entire study period. At the monthly scale, the months of February to April consistently concentrate the highest temperatures throughout the study period. These results constitute a climatological baseline for future research in West African coastal urban settings, particularly regarding the specific role of nocturnal warming in aggravating health risk.

STATEMENTS ON COMPLIANCE WITH ETHICAL STANDARDS

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Disclosure of conflict of interest

The authors declare no conflicts of interest.

Availability of data and materials

The datasets analyzed during the current study are available from the corresponding author on reasonable request.

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