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Analysis of temperature variability utilising Mann–Kendall and Sen's slope estimator tests in the Accra and Kumasi Metropolises in Ghana

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Abstract

Temperature variability may have direct and indirect impacts on the environments of the Accra and Kumasi Metropolises in Ghana. This study analysed temperature and trends in temperature in both cities using in-situ measurements from one meteorological station in both cities from 1986 to 2015. The temperature indices were computed using the RClimdex package from the Expert Team on Climate Change Detection Monitoring Indices (ETCCDMI). The temperature time series was pre-whitened before the Mann–Kendall trend and Sen's slope estimator analysis were applied. Initial analysis revealed minimal variation in temperature in both cities. The results from the analysed temperature indices revealed an increase in warm days and a general rise in the minimum temperature compared to maximum temperatures. Mann Kendall and Sen's slope revealed significant trends in the annual and seasonal (dry and wet seasons) in minimum temperature in both cities. These might lead to an increased rate of heat-stressed diseases and an overall rise in urban warming in both cities. The analysis of temperature, indices and trends provided comprehensive insights into the temperature of Accra and Kumasi. The results highlight the essence of evaluating temperature indices and trends in light of Climate Change concerns. It is recommended that urban green and blue spaces should be incorporated into land use plans as these policy directions can aid regulate the temperature in both cities.

Keywords: Temperature, Trends, Mann Kendall, Sen's slope, RClimdex, Urban warming, Climate change

Introduction

Globally, temperature is considered an important variable within the climate system and it is chosen as one of the standard variables for analysis (Kajtar et al. 2021; Ragatoa et al. 2018). Temperature variability may lead to a rise in the frequency, magnitude and seasonality of extreme events which are likely to happen in the future (van der Wiel and Bintanja 2021).

Temperature indices are essential indicators used for monitoring and detecting variability (Qaisrani et al. 2021). Various groups of indices have been invented using percentiles and thresholds. The most popular and utilized is the group of indices of the Expert Team on Climate Change Detection and Indices (ETCCDI), sponsored by the Commission for Climatology of the World Meteorological Organization (WMO), the Joint Commission for Oceanography and Marine Meteorology (JCOMM) and by the Climate Variability and Predictability (CLIVAR) project (Faye and Akinsanola 2022). Temperature viability studies have been done at the global level (Hansen et al. 2021), national level using Ghana and at the local level using the city of Abuja in Nigeria and Shenyang in China (Mahmoud 2016; Yang et al. 2021).

Karaburun et al. (2011) investigated the evolution of mean, minimum and maximum temperatures in the monthly, seasonal and annual temperatures in Istanbul utilising the Mann–Kendall test and revealed positive trends in annual averages and average maximum temperature at both 95% and 99% significance. Larbi

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et al. (2018) investigated trends in annual temperature extremes using the Vea Catchment (one of the sub-catchments within the white Volta basin) in Ghana from 1985 to 2016 using quality-controlled weather station data. The non-parametric Mann–Kendall test and Sen's slope estimator were utilised to detect trends in temperature. A general warming trend was observed over the Vea Catchment. The work of Gadedjisso-Tossou and Adjegan (2021) investigated trends in monthly and annual minimum and maximum temperature from 1977 to 2012 utilising the Mann–Kendall test and Sen's slope to evaluate the significance of selected cereal crops utilising multiple regression analyses. The results from the regression analyses revealed non-linear yield responses to alterations in temperature. It was however concluded that temperature variability affected the productivity of the cereal crops negatively.

According to Oduro et al. (2022), the temperature of Ghana increased by about 1.0 °C between 1960 and 2000. Ghana has a mean annual temperature ranging from 24 °C to 30 °C (Asante and Amuakwa-Mensah 2015). Temperature has been increasing more rapidly in the Northern than Southern parts of Ghana (Minia 2008). The mean annual air temperature increased by 0.9 °C between 1960 and 2001 along the coast of Ghana. The maximum temperature increased by 2.5 °C whilst the minimum temperature also rose by 2.2 °C during the same period (Dontwi et al. 2008). Subaar et al. (2018) analysed the daily mean air temperature from 1990 to 2009 in Wa, Upper West Region, Ghana. The study revealed a rise in annual mean temperature of 0.4 ℃. Klutse et al. (2020) predicted temperature and its probable consequences on smallholder farming systems in the Northern Regions of Ghana. The analysed temperature data from 1961 to 2000 indicated that the average annual temperature across Ghana increased by 1.0 ℃ (Klutse et al. 2014).

Temperatures will increase by 1.1–1.3 °C for southern Ghana and up to 1.4 °C for Northern Ghana by 2030 (Läderach, 2011). The mean annual temperature will rise progressively by 2050 by 1.7–2.1 °C in southern Ghana and up to 2.5 °C in the northern parts of Ghana. There have been rising temperatures in different study locations in Ghana due to climate change (Adusu et al. 2022; Asare-Nuamah and Botchway 2019; Kabo-Bah et al. 2016).

Ghana has experienced the impacts of temperature variability with an increase of 1.0 °C in temperature from 1960 to 2000 (Oduro et al. 2022). The pressing issues about the consequences of temperature variability include but are not limited to: The agricultural sector, which consists of mainly small-scale farmers who have the least resources to invest in and are vulnerable to the potential impacts of temperature variability. Estimates of the cost of environmental degradation in 2006 indicated a loss of 10% of Gross Domestic Products (GDP) yearly. This is attributed to the unsustainable management of lands and forests (MESTI 2013). The impacts are land degradation, deforestation and biodiversity loss but deforestation stood out within the Ghanaian Landscape (Kumeh et al. 2022; Kyere-Boateng and Marek 2021).

A handful of works to determine trends in temperature in Ghana exist in the literature. Most of them were done at national and regional levels (Baffour-Ata et al. 2021; Boansi et al. 2017; Dankwa et al. 2021; Issahaku et al. 2016). Adu-Prah et al. (2019) used trajectory and time series analysis of temperature anomalies across the agroecological zones of Ghana. The study revealed that the local temperature increased for the study period from 0.5 ℃ to 1.0 ℃. Asare-Nuamah and Botchway, (2019) utilised temperature data from 1989 to 2015 to ascertain the characteristics and trends in temperatures across the agroecological zones in Ghana. Oduro et al. (2022) investigated seasonal and annual trends from 1901 to 2018 in Ghana. The findings revealed that there has been a significant rise in both the annual and seasonal temperatures of minimum and maximum temperatures whilst mean temperature recorded a steady increment over the study period. Finally, Asamoah and Ansah-Mensah (2020) investigated the temporal variations in temperature in Bawku, Upper East Region of Ghana from 1976 to 2015. The mean temperature revealed a significant increase. In addition, it was observed that day and night temperatures increased during the study period (Asamoah and Ansah-Mensah 2020).

Although temperature has been analysed throughout Ghana in seminal works (e.g. Abbam et al. 2018; Asamoah and Ansah-Mensah 2020; Issahaku et al. 2016), limited attention has been given to the analysis of temperature time series, temperature indices and temperature trends in Accra and Kumasi. Both cities are the most urbanised centres in Ghana and led to the transformation of green areas into urban/built-up areas (Addae and Oppelt 2019; Frimpong and Molkenthin 2021; Ghana Statistical Service (GSS) 2014a, b). This research, therefore, chose these two cities due to the high levels of land use land cover changes. The research seeks to fill this knowledge gap by analysing the maximum and minimum temperatures, indices and trends (seasonal and annual) of both cities. In this research, the dry seasons were made up of the months; November, December, January, February and March. On the other hand, the wet season consisted of the months; April, May, June, July, August, September and October as also used in the work of (Amoah et al. 2016).

Material and methods

Case study cities (Accra and Kumasi)

Accra acts simultaneously as the capital of the Greater Accra Region and Ghana. The capital is in the south-eastern portion of the coast of the Gulf of Guinea. Geographically, Accra is bounded on the north by latitude 5.41° N, on the south by the Gulf of Guinea, on the east by longitude 0.30° E and on the west by longitude 0.17° W (Ghana Statistical Service (GSS) 2014a, 2014b) (Fig. 1). The Accra Metropolitan Assembly consists of the Ablekuma, Ayawaso, Kpeshie, Okaikoi and Osu Klottey administrative boundaries (Ghana Statistical Service (GSS), 2014a) with a population of 2,066,275 and it is the most populated city in Ghana (Ghana Statistical Service (GSS) 2021).

Kumasi, the capital of the Ashanti Region is found between Latitude 6.35° N and 6.40° S and Longitude 1.30° W and 1.35° E. It is about 270 km north of Accra (Ghana Statistical Service (GSS) 2014a, b) (Fig. 1). The Kumasi Metropolitan Assembly was made up of the Asawase, Asokore-Mampong, Asokwa, Bantama, Kwadaso, Manhyia, Nhyiaeso, Oforikrom, Suame, Subin and Tafo (Ghana Statistical Service (GSS) 2014a, b) with a population of 1,823,316 and it is the second most populated city in Ghana (Ghana Statistical Service (GSS) 2021).

Dataset utilised

Temperature datasets comprising daily values of minimum and maximum temperature spanning from 1st January 1986 to 31st December 2015 were used for this retrospective study. The study period was chosen as it spanned 30 years and the complete dataset was readily available for both cities.

The dataset was obtained from the Ghana Meteorological Agency (GMA) stations (Kotoka International Airport weather station in Accra and the Kumasi weather station). It was made up of daily maximum and minimum temperatures.

Methods

Initial data analysis

Preliminary analysis was run for the temperature dataset. Time plots were constructed for daily maximum and minimum temperature. This provided a general overview and insights into the distribution of the data.

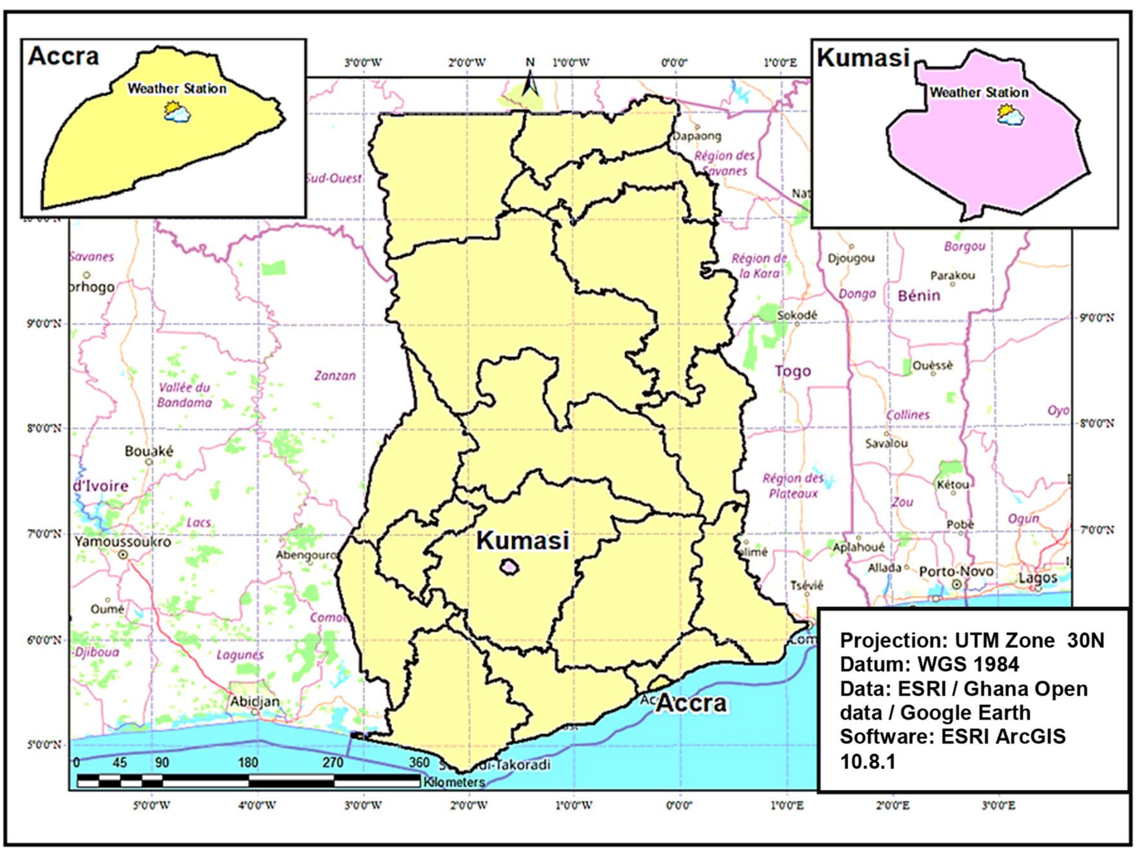

Fig. 1 Map of Ghana showing both cities and their meteorological stations

Temperature indices

Daily values of maximum and minimum temperature datasets from 1986 to 2015, were used to calculate five temperature indices as recommended by the Joint CCl/CLIVAR/JCOMM Expert Team (ET) on Climate Change Detection and Indices (Frich et al. 2002) (Table 1).

The indices not calculated were rainfall indices. The other temperature indices were not applicable in the study areas since both cities are situated in the tropics, such as the number of frost days, summer days, ice days, and tropical nights (Parsons et al. 2022; WMO 2021). Data quality checks were done to identify missing values, outliers, and days when the minimum temperature was greater than the maximum temperature. Finally, the input file of the adjusted daily maximum temperature and daily minimum temperature was used to calculate the temperature indices (Table 1). The RClimdex was used for the computation of temperature indices and trends in the temperature dataset. Initially, it was employed to check the quality of the data. RClimdex provided insights into extreme variations in temperature (Zhang and Yang 2004).

Trend analysis methods

Non-parametric methods were used to detect significant trends in the temperature time series. Since the temperature data was not normally distributed, the Mann–Kendall and Sen's slope estimator were used to detect trends and the slopes respectively.

Serial Correlation (seasonal and annual) The serial correlation was removed from the temperature data to prewhiten the dataset before using the Mann–Kendall test (von Storch and Navarra 1999). The study incorporated this suggestion before utilising the Mann–Kendall test and Sen's slope estimator.

Table 1 Calculated temperature indices for the study areas by ETCCDI

ID	Type of Indices	Definition	Unit
	Percentile Based Indices		
TX10p	Cold days	Percentage of days when TX < 10th percentile	%
TN10p	Cold nights	Percentage of days when TN < 10th percentile	%
TX90p	Warm days	Percentage of days when TX > 90th percentile	%
TN90p	Warm nights	Percentage of days when TN > 90th percentile	%
DTR	Diurnal temperature range	Monthly mean difference between TX and TN	days

The possible statistically significant trends in the temperature data ($x_1, x_2, \ldots, x_n$) were assessed utilising the following procedures:

1. The lag-1 serial correlation coefficient (r_1) was computed. The lag-1 serial correlation coefficient of sample data x_i was computed using the equation below (Kendall and Stuart 1961).

$$r_1 = \frac{\frac{1}{n-1}\sum_{i=1}^{n-1}(x_i - E(x_i))(x_{i+1} - E(x_i))}{\frac{1}{n}\sum_{i=1}^{n}(x_i - E(x_i))} \quad (1)$$

$$E(x_i) = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (2)$$

where $E(x_i)$ is the average of the sample data and n is the sample size.

2. If the computed r_1 was not significant at the 5% level, then the Mann–Kendall test and Sen's slope estimator were applied to the original values of the time series.

3. If the computed r_1 was significant, before applying the Mann–Kendall test and Sen's slope estimator, the 'pre-whitened' time series might be acquired as ($x_2 - r_1 x_1$, $x_3 - r_1 x_2$, ..., $x_n - r_1 x_{n-1}$).

The critical value of r_1 for a given significance level depended on whether the test was one-tailed or two-tailed. The alternative hypothesis for the one-tailed hypothesis was usually that the true r1 is greater than zero, whereas the alternative hypothesis for the two-tailed test was that the true r1 is different from zero, with no indication of whether it was positive or negative. According to (Anderson 1942), the probability limits of an independent series for r_1 were computed as;

$$r_1 = \begin{cases} \frac{-1+1.645\sqrt{n-2}}{n-1}, & \text{one} - \text{tailed test} \\ \frac{-1\pm 1.96\sqrt{n-2}}{n-1}, & \text{two} - \text{tailed test} \end{cases} \quad (3)$$

where n was the sample size.

Both one-tailed and two-tailed tests were employed since there was reason to suspect both positive and negative autocorrelation was present in the temperature dataset.

Mann–Kendall trend test The Mann–Kendall test statistic S (Kendall 1955; Mann 1945) was computed as;

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} \operatorname{sgn}(x_j - x_i) \quad (4)$$

where,

n = the total number of data points.

x_i and x_j = data values in time series i and j (j > i), respectively and $sgn(x_j - x_i)$ is the sign function:

$$sgn\left(x_j - x_i\right) = \begin{cases} +1, \text{if } x_j - x_i > 0 \\ 0, \text{if } x_j - x_i = 0 \\ -1, \text{if } x_j - x_i < 0 \end{cases} \quad (5)$$

The variance was computed as;

$$Var\,(S) = \frac{n(n+1)(2n+5) - \sum_{i=1}^{m} t_i\,(t_1-1)\,(2t_1+5)}{18} \quad (6)$$

where,

n = the number of data points,

m = the number of tied groups and t_i denotes the number of ties to the extent i. A tied group is a set of sample data having the same value.

In the case, where the sample size, n > 10, the standard normal test statistic Z_S was computed using the equation;

$$Z_S = \begin{cases} \frac{S-1}{\sqrt{Var\,(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1,}{\sqrt{Var\,(S)}}, & \text{if } S < 0 \end{cases} \quad (7)$$

Positive values of Z_S indicated increasing trends while negative Z_S values showed decreasing trends.

Sen's slope estimator

Sen (1968) devised the non-parametric method for the estimation of the slope of a trend in the sample of N pairs of data:

$$Q_i = \frac{x_j + x_k}{j - k} \quad \text{for } i = 1, \ldots, N, \quad (8)$$

where, X_j and X_k = the data values at times *j* and *k* (j > k), respectively.

If there is only one datum in each period, then $N = \frac{n(n-1)}{2}$. where n = number of periods.

If there are multiple observations in one or more time periods, then $N < \frac{n(n-1)}{2}$. where n = total number of observations.

The *N* values of *Qi* are ranked from the least to the highest and the median slope or Sen's slope estimator was calculated as

$$Q_{med} = \begin{cases} Q_{\left[\frac{N+1}{2}\right]}, & \text{if N is odd} \\ \frac{Q_{\left[\frac{n}{2}\right]} + Q_{\left[\frac{N+2}{2}\right]}}{2}, & \text{if N is even} \end{cases} \quad (9)$$

The Q_{med} sign reflects the data trend, while its value indicates the steepness of the trend. To determine whether the median slope is statistically different from zero, the computation of the confidence interval of Q_{med} at a specific probability is done.

The confidence interval about the time slope was calculated as:

$$C\alpha = Z_{1-\alpha/2}\sqrt{Var(S)}, \quad (10)$$

where *Var*(*S*) is defined in Eq. 8.14 and $Z_{1-\alpha/2}$ is obtained from the standard normal distribution table.

In this study, the confidence interval was computed at a significance level of $\alpha = 0.05$.

$$\text{Then, } M_1 = \frac{N - C\alpha}{2} \text{ was computed} \quad (11)$$

The positive values indicated an increasing trend whilst negative values denoted a decreasing trend in the time series of analysed temperature.

The XLSTAT was utilised to compute trends (Mann Kendall and Sen's slope) in the temperature data. The XLSTAT is an add-in tool in Excel (Addinsoft 2019).

Results

Annual plots of temperature for both cities

Both cities exhibited fairly constant steadiness in temperature throughout the study period. Mean values overlapped. Nonetheless, it was apparent that Kumasi slightly yielded higher mean values for maximum temperature. The values ranged from 30.9 °C (1996) to 32.2 °C (2010) compared to values for Accra that ranged from 29.6 °C to 32 °C that occurred in 2003 and 1998 respectively.

Generally, Accra received higher values for minimum temperature compared to Kumasi. Likewise, maximum temperature and steadiness were observed throughout the study period. The values for Accra ranged between 23.7 °C (1988 and 1992) and 25 °C (2010). On the other hand, values for Kumasi were between 21.5 °C (1986) and 22.8 °C (1998). Interestingly, there was an increase in the measured average maximum and minimum temperature of both cities in 1987, 1998 and 2010 (Fig. 2). There was also a sudden drop in the years 2003 and 2012 for the maximum and minimum temperature, respectively for Accra.

Analysis of temperature indices

A. Cold days—percentage of days when the maximum temperature was less than the 10th percentile

Accra had a decline in values from 1986 to 1987. A few fluctuations followed until it dropped significantly in 1995. Again, there was a rise with variations till it peaked in 2001. A sudden decrease followed by fluctuations that led to its bottoming out in 2011. A sudden rise was

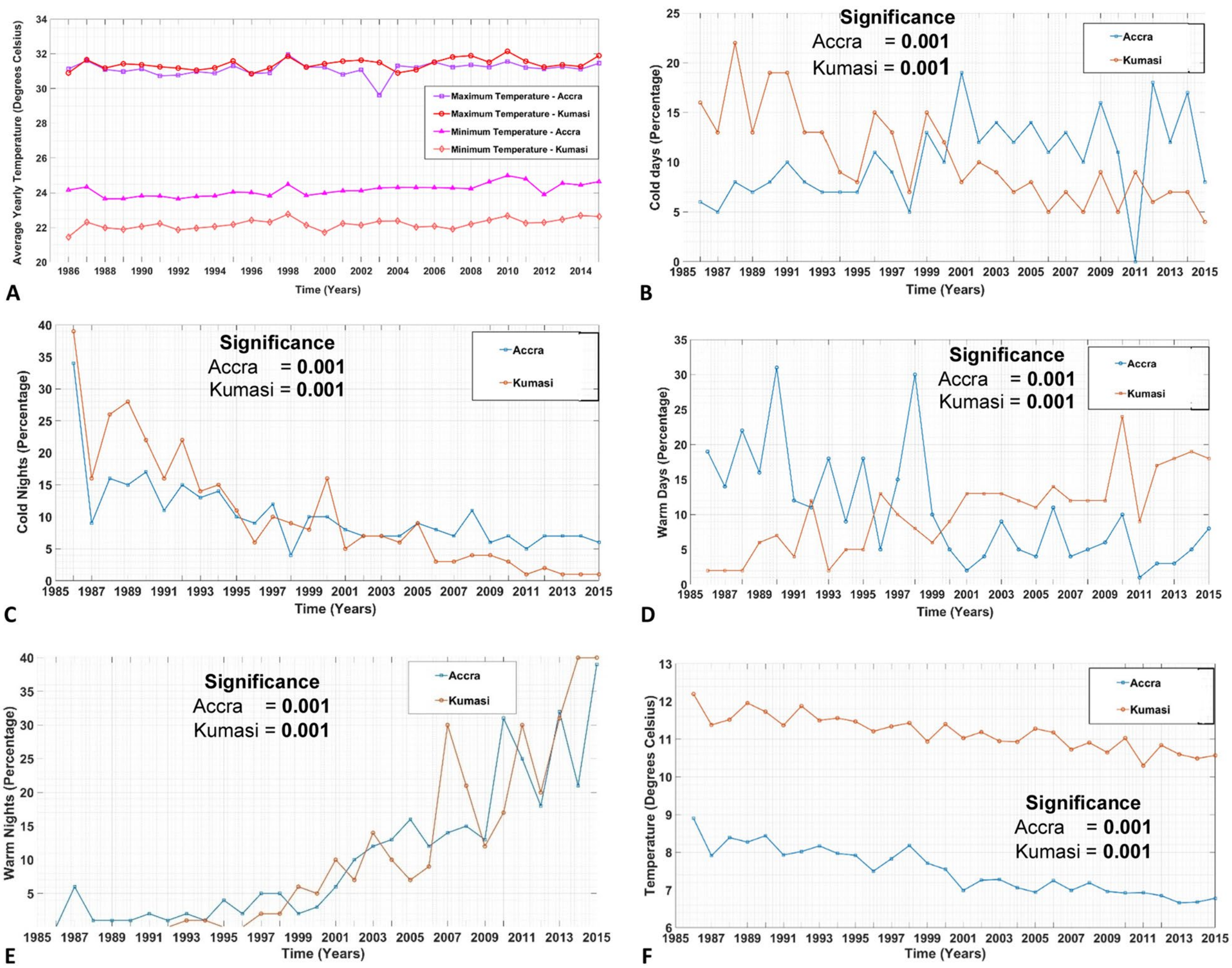

Fig. 2 **A** Yearly average temperature **B** Cold Days **C** Cold Nights **D**. Warm Days **E** Warm Nights **F** Diurnal Temperature Range

observed and afterwards, fluctuations in values occurred that led to a decline in the last year.

Just like Accra, Kumasi also experienced a decline from 1986 to 1987. It dropped drastically, followed by steady variations before its lowest value in 2015. The results were significant in both cities (Fig. 2).

In Kumasi, there was also a drastic decrease from 1986 to 1987, and it rose until 1989. Fluctuations followed before the year 2000 when the highest value was measured. There was a sudden drop in the subsequent year. Steady fluctuations followed this until 2015. This index was significant in both cities (Fig. 2).

B. Cold nights—percentage of days when minimum temperature was less than the 10th percentile

It was observed that there was a sudden decline from 1986 to 1987 in Accra. However, it rose afterwards, which was followed by fluctuations. These fluctuations continued until 2012. Then, steady values were yielded in 2014, followed by a drop in the last year of the study. Then, it suddenly dropped in the subsequent years till 2015 (Fig. 2).

C. Warm days—percentage of days when the maximum temperature was greater than the 90th percentile

In Accra, the percentage of the number of days fluctuated for this index from 1986 to 1990, with a slight decrease in the ensuing year. However, there were fluctuations before 1996. A sudden rise was seen up till 1998. Moreover, it was followed by a drop in the number of warm days in 2001. After that, values began rising again with few fluctuations before 2011. Finally, there was a steady rise before 2015 (Fig. 2).

Kumasi experienced steadiness from 1986 to 1988. This was followed by a rise into 1990. After that, the gradual decline in percentages followed until it bottomed out in 1993. However, it was noticed that sharp fluctuations abruptly followed gradual fluctuations in percentages before they peaked in 2010. There was a sudden decline in 2011, and a rise was observed, afterwards by a steady increase until 2014. Finally, a gradual decrease was noticed in 2015. The index was significant in both cities (Fig. 2).

D. Warm nights—percentage of days when minimum temperature was greater than the 90th percentile

Generally, it was observed that the number of warm nights revealed a constant rise throughout the study period. There was a rise from 1986 to 1987 for Accra. The values exhibited steady fluctuations before the year 1999. However, from 1999, values rose into 2005. It was observed that percentages dropped before the year 2012, fluctuations followed into 2014 and a sharp rise was noticed in 2015 (Fig. 2).

In Kumasi, there were no initial recordings (i.e. no values were measured) before 1993. There were a sudden rise and few fluctuations till 2006. Sharp fluctuations followed this until 2014. Interestingly, the percentage for 2014 remained unchanged in 2015. The index was significant in both cities (Fig. 2).

E. Diurnal temperature range (DTR)—monthly mean difference between maximum temperature and minimum temperature °C)

Similar patterns were observed for both cities, but Kumasi recorded higher DTR values compared to Accra.

The monthly mean difference between the maximum and minimum temperatures revealed a gradual decrease from 1986 to 1988 in Accra. However, this was followed by fluctuations which generally depicted a downward trend throughout the study period (Fig. 2).

Similarly, in Kumasi, there was a decrease in values from 1986 to 1987. This was followed by a lot of steady fluctuations with a decreasing trend but remained stable for the last three years. The diurnal temperature range was significant in both cities (Fig. 2).

Trends in temperature indices (1986–2015)

The calculated temperature indices revealed positive trends per year in both cities. The percentile-based indices for temperature produced 0.08 (Kumasi) and 0.06 (Accra) for cold days (Table 2). Cold nights revealed 0.09 for Accra and 0.10 (Kumasi) while warm days produced 0.13 for Accra and 0.06 for Kumasi. However, the warm nights yielded positive trends of 0.11 (Accra) and 0.13 (Kumasi).

The annual monthly maximum value of daily maximum temperature and annual monthly maximum value of daily minimum temperature yielded 0.01 °C. On the other hand, the monthly minimum value of daily maximum temperature and monthly minimum value of daily minimum temperature produced 0.02 °C for Accra. In the case of Kumasi, the annual monthly maximum value of the daily maximum temperature and the monthly minimum value of the daily minimum temperature was 0.02 °C. The monthly maximum temperature value of daily minimum temperature and monthly minimum value of daily maximum temperature recorded 0.01 °C. Finally, the DTR produced 0.01 for both cities (Table 2).

Serial correlation (seasonal and annual)

The serial correlation coefficients were positive. The strongest serial correlation was obtained for maximum temperature. The lag 1 series produced lower values for both dry and wet seasons for rainfall. The lag 1 in this research referred to the relationship between a present temperature value and its preceding value. On the other hand, the annuals recorded a higher correlation value

Table 2 Trends in temperature indices for both cities

Temperature Indices	Accra	Kumasi	Unit/year
Cold Days	0.08	0.06	days
Cold Nights	0.09	0.10	days
Warm Days	0.13	0.06	days
Warm Nights	0.11	0.13	days
Annual monthly maximum value of daily maximum temperature	0.01	0.02	^{O}C
Annual monthly maximum value of daily minimum temperature	0.01	0.01	^{O}C
Annual monthly minimum value of daily maximum temperature	0.02	0.01	^{O}C
Annual monthly minimum value of daily minimum temperature	0.02	0.02	^{O}C
Diurnal Temperature Range	0.01	0.01	^{O}C

Table 3 Lag 1 serial correlation coefficient

Meteorological Variable	Season	Accra	Kumasi
Maximum Temperature	Dry Season	0.17	0.61
	Wet Season	0.84	0.88
	Annual	0.79	0.89
Minimum Temperature	Dry Season	0.52	0.38
	Wet Season	0.74	0.66
	Annual	0.75	0.50

than seasonal variability except for the annual minimum temperature for Kumasi. Generally, Kumasi yielded a better serial correlation coefficient than Accra. Maximum temperature yielded a higher serial correlation coefficient for all except for the dry season for the maximum temperature of Accra. Minimum temperature yielded moderate values for the serial correlation coefficient for all seasons and annuals for both cities (Table 3).

Mann Kendall and Sen's slope

The Mann Kendall and Sen's slope provided insights into the trends with their statistical significance. The Mann–Kendall test and Sen's slope estimator were applied to the original values of the series because the calculated serial correlation coefficient was not significant at a confidence level of 95%.

The maximum temperature had trends in the dry season of Accra, the wet season and the annual of Kumasi. Minimum temperature revealed trends for both seasons and annuals for both cities (Table 4).

The magnitude of change i.e. Sen's slope revealed that the wet season of the minimum temperature for Accra was 0.191 which was the highest. The least was revealed at the annual maximum temperature of Kumasi throughout the study period (Table 4).

Discussions

Annual plots of temperature for both cities

Temperature variations were minimal in both cities due to the local climate. The temperature did not substantially differ since the cities are 250 km apart and this attributed to the less variation in temperature as the highest correlation was revealed for (maximum and minimum temperature Amoako and Boamah, 2015; Dickson et al. 1988). The increase in the measured average maximum and minimum temperatures for 1987, 1998 and 2010 could be due to inherent characteristics present in the temperature dataset. The sudden decrease in the maximum and minimum temperature for Accra could be considered, an outlier for the entire temperature dataset (Peterson et al. 1998).

This preliminary analysis stands to serve as a basis for the analysis of temperature in both cities and will serve as a rudimentary source of information for other researchers for future studies.

Temperature indices

It was generally observed that there were decreasing trends in the cold nights compared to increasing trends in the warm nights. These results agreed with the works of (Klein Tank et al. 2006; New et al. 2006; You et al.

Table 4 Summary of Mann–Kendall and Sen's slope tests

Variable	Station	Period	Mann–Kendall	
			P-Value	Trend (Sen Slope)
Maximum Temperature	Accra	Dry	0.032*	Trend detected (0.045)
		Wet	0.187	No trend
		Annual	0.094	No trend
	Kumasi	Dry	0.199	No trend
		Wet	0.010*	Trend detected (0.114)
		Annual	0.042*	Trend detected (0.015)
Minimum Temperature	Accra	Dry	0.001*	Trend detected (0.185)
		Wet	0.001*	Trend detected (0.191)
		Annual	0.001*	Trend detected (0.032)
	Kumasi	Dry	0.014*	Trend detected (0.110)
		Wet	0.008*	Trend detected (0.123)
		Annual	0.001*	Trend detected (0.019)

*Statistically significant trends at 5% significance level

2011). There were fluctuations in both the cold days and warm days. However, the bottoming of cold days might be due to inherent characteristics present in the temperature dataset (Peterson et al. 1998). Minimal increasing trends were obtained in DTR. This could be attributed to the increase in the minimum temperatures in the three decades of study as found in the work of (Easterling et al. 1997). This outcome attests to the increased urban warming experienced in both cities.

The monthly mean difference between the maximum and minimum temperature showed significant positive trends in both cities. The decrease in the DTR may be an indicator of urban warming in both cities. This was similar to the findings of (Easterling et al. 1997), where DTR increased significantly. Earlier works have revealed that the minimum temperature has increased faster than the maximum temperature globally (Alexander et al. 2006) and locally in the Greater Accra Region of Ghana (Wemegah et al. 2020).

The significance of increasing warm days in both cities reaffirmed the impacts of temperature changes. The rise in warm days might have led to discomfort amongst the populace and increased cooling systems in houses and vehicles in both cities. This outcome corroborates the outcome of Mahmoud (2016) that used Abuja, Nigeria as a test site.

Warm nights have increased in both cities agreeing with earlier works (Wang et al. 2020; Yeh et al. 2021). It has made people who cannot afford the cooling systems in their homes sleep on the compounds of their homes, especially when there is no supply of electricity.

Previous researches have established the nexus between temperature variability and human health. This study agrees with Chan et al. (2012) that increasing warm days and warm nights may affect the health of the aged, especially it could lead to respiratory disorders. It is also asserted that malaria increases with extreme temperatures (Nelson and Agbey 2005). Danuour et al. (2010) revealed a positive correlation between maximum temperature and the incidence of malaria. In the case of infants, heat rashes develop on their skins (Basagaña et al. 2011; Xu et al. 2012). This is very discomforting for babies (Basagaña et al. 2011; Xu et al. 2012). The findings in this research suggest that there could be an impact of heat influx on the populace in both cities. The findings agreed with the earlier studies of (Alexander et al. 2006; Volodin and Yurova 2013) that indicated that urban warming was caused by rises in warm extremes.

Therefore, the consequences of increasing warm days and nights and reducing the cold days and nights may lead to increased heat-stressed diseases associated with the lungs and skins of humans in both cities. Health practitioners, especially those in the field of dermatology and pulmonology, may benefit from this outcome by educating their patients on the effects rising temperature may have on them and could also design mitigation measures to help guard their patients against the harsh extremes of temperature in both cities. The analysis using the temperature indices provided in-depth comprehension of the meteorological variables (Iyakaremye et al. 2021).

Trends in temperature (indices, seasonal and annual)

The trends identified a higher rise in the number of warm days and warm nights in both cities compared to the number of cold days and cold nights which were similar to the findings of Huong and Pathirana (2013). The annual monthly maximum value of daily minimum temperature, the annual monthly maximum value of daily minimum temperature and the diurnal temperature range produced the same values for both cities in Table 2. This confirms that there is less variation in temperature as similar trends were found in this research as found in previous literature (Amoako and Boamah 2015; Dickson et al. 1988). The higher variation in the annual monthly minimum value of daily maximum temperatures of Accra compared to Kumasi may be attributed to the higher number of warm days in Accra compared to Kumasi.

The increasing trends in temperature as found in this research are consistent with previously published works in different geographical locations in Ghana that revealed increasing temperature (Kabo-Bah et al. 2016; Nkrumah et al. 2014). There was an increase in temperature in both the maximum and minimum temperatures in both cities and it was in line with the results in the works of (Gocic and Trajkovic 2013; Oduro et al. 2022), where increasing trends were identified in both the annual and seasonal maximum and minimum air temperature time series analysis. There were increasing trends in annual maximum temperature ranging between 0.5 °C/year to 0.7 °C/year at the Negotin weather station. However, the annual minimum temperature ranged between 0.3 °C/year to 0.4 °C/year (Gocic and Trajkovic 2013). This was higher than the values obtained in this research. This higher variation may be due to the differences in the biophysical factors at the different geographical locations. In addition, the research of Mahmoud (2016) revealed that Abuja has witnessed a minimum increase of 8 °C from 1986 to 2014 (i.e. 0.28 °C/year) whilst the annual average temperature has also increased by 0.83 °C while the annual average maximum temperature also increased by 1.6 °C during the 32 years of study in Istanbul (Karaburun et al. 2011). The works of (Karaburun et al. 2011; Mahmoud 2016) recorded higher changes in the temperature as compared to this research. The results in the work also agree with the research of (MESTI 2013) which indicated the temperature of Ghana had increased by about 1.0 °C between 1960 and 2000. Again, it collaborates with the works of Dontwi et al. (2008) that the maximum temperature rose by 2.2 °C from 1960 to 2001 and Adu-Prah et al. (2019) also concluded that was a rise in temperature between 0.5 °C to 1.0 °C from 1981 to 2009 in Ghana, although the values produced in Table 2 were lower. It is therefore evident that there are increasing trends even though the values differ amongst the various researches, especially in Ghana. The differences could be attributed to the different ranges of temperature data utilised and the extent of coverage in terms of physical/administrative borders.

It was interesting that for maximum temperature; the dry, wet and annual of lag 1 serial correlation coefficient produced higher values in Kumasi compared to Accra whilst the reverse was found for minimum temperature. This may be linked to the lower range of recorded values for maximum temperature in Kumasi and the lower range of values for minimum temperature in Kumasi.

The Mann Kendall and Sen`s slope tests revealed no trends in the maximum temperature in the wet season and annual assessment of Accra but a significant trend was detected in the dry season. The reverse was found in Kumasi as no trend was found in the dry season of Kumasi. However, trends were detected in the wet and annual of Kumasi. The wet, dry and annual for minimum temperatures had trends, meaning the results were significant in both cities. This may explain the fact that the minimum temperature has been rising in both cities and it agrees with earlier works that minimum temperatures are rising higher as compared to maximum temperature (Alexander et al. 2006; Stone and Weaver 2002).

Urbanisation has led to the transformation of green areas (agricultural and forestlands) in both cities have attributed to urban temperature changes (Frimpong and Molkenthin 2021; Owusu 2018). The urban population have also increased and has necessitated the need for more housing units and other infrastructure in both cities (Frimpong and Molkenthin 2021).

Increasing trends in both seasonal and annual temperature could lead to consequences such as dry spells and droughts. This has an enormous negative impact on food security, gross domestic products and agriculture (MESTI 2013). Aside from the effects of temperature changes on the agricultural sector, it may also lead to the loss of arable lands, forestlands, biodiversity, sensitive habitats and the drying up of water bodies. The rising temperature could also reduce surface and groundwater resources. Policymakers may use this outcome as a springboard for developing information for the needed populace to reduce vulnerabilities to extreme temperature variations and also aid in the planning of the mitigation actions needed to avert the continuous increases in temperature.

Research conclusions and future guidelines

The historical temperature data (1986–2015) analysis using temperature indices revealed alterations in the temperature variables. This enabled an in-depth comprehension of trends in temperature. The temperature indices analysed revealed that minimum air temperature has been altered significantly with positive trends in both cities. Besides, it was confirmed in the increasing number of warm days and nights and a significant reduction in cold days and nights in both cities. The trends revealed increasing warm days and nights and a reduction in the number of cold days and nights. The increasing warming trends may also be indicative of urban warming in both cities.

The seasonal trend analysis also revealed a warming trend in temperature. Except for the wet and annual of Accra and the dry season of Kumasi (no trend), varying trends were observed for (dry, wet and annual) of minimum temperatures for both cities. However, the maximum temperature of both cities had trends in the dry seasons for Accra and the wet and annual for Kumasi.

The temperature indices and the seasonal trend analysis revealed increasing trends and served as a valuable means of communicating the impacts of temperature variability.

The research utilised a meteorological dataset for the analysis of temperature in both cities. Nevertheless, it provided a foundation for future temperature studies. The research, therefore, suggests the following guidelines.

Temperature analysis can make use of other sources of temperature data, such as global gridded products. For instance, data from the Climate Research Unit from the University of East Anglia and the MODIS climate modelling grid could be used for an in-depth analysis of the long-term temperature. The resolution may be 0.5° by 0.5° or 0.25° by 0.25°. There are merits to using gridding products over in-situ measurements of temperature (see Donat et al. 2013; Frich et al. 2002). Again, the focus of this research was not on temperature prediction. The data mining technique, k-Nearest Neighbour (see Jan et al. 2008; King et al. 2015) can be utilised for the prediction of temperature. The forecasting of temperature will provide more insights for environmental managers and planners in Ghana.

Both cities had only one meteorological station and this might have affected the temperature variability. This led to flaws in data measurement. There should be the establishment of additional weather stations in both cities such that, there could be sharing of tools, resources and information. There could be the establishment of an online portal to catalogue the activities of recording weather station parameters from all the synoptic stations located in both cities. This enables climate variables to be recorded from synoptic weather data into the portal. The activities of recording the weather parameters in the cities will become more visible and will enhance data exchange. It may also include materials that would describe workflows to upscale monitoring schemes.

The increase in vegetated areas is the most applied mitigation measure adopted for the regulation of temperature (Kikegawa et al. 2006). Again, urban blue spaces can aid in the provision of ecosystems and support transportation activities in cities (Coutts et al. 2012; Völker et al. 2013) and these strategies should be adopted in both cities.

The key findings in this research will serve as baseline information for other scientists, end-users and policymakers regarding the analysis of temperature variability in both cities.

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Author contributions
BFF and FM conceptualised the research and the applied methods; BFF curated the data, did the formal analysis, utilised the software and wrote the initial draft; FM provided the resources and supervised the research; All authors aided in the administration of the project, read and approved the final manuscript.

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Availability of data and materials
Derived data supporting the findings of this study are available from the corresponding author (BFF) on request.

Declarations

Competing interests
The authors declare no competing interests.

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