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Analysis of Changes of Extreme Temperature during June to August Season over Tanzania

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Abstract

Natural and human systems are exposed and vulnerable to climate extremes, which contributes to the repercussions of climate variability and the probability of disasters. The impacts of both natural and human-caused climate variability are reflected in the reported changes in climate extremes. Particularly at the local community levels in the majority of the regions, there is currently a dearth of information regarding the distribution, dynamics, and trends of excessive temperatures among the majority of Tanzanians. Over the years 1982-2022, this study examined trends in Tanzania's extreme temperature over the June to August season. Based on the distinction between absolute and percentile extreme temperatures, a total of eight ETCCDI climate indices were chosen. Mann-Kendall test was used to assess the presence of trends in extreme climatic indices and the Sen's Slope was applied to compute the extent of the trends in temperature extremes. The study showed that in most regions, there is significant increase of warm days and nights while the significant decrease of cold days and nights was evident to most areas. Moreover, nighttime warming surpasses daytime warming in the study area. The study suggests that anthropogenic influences may contribute to the warming trend observed in extreme daily minimum and maximum temperatures globally, with Tanzania potentially affected, as indicated in the current research. The overall results of this study reflect patterns observed in various regions worldwide, where warm days and nights are on the rise while cold days and nights are diminishing.

Keywords

Indices, Warm Days and Nights, Cold Days and Nights, ECA&D, Tanzania

1. Introduction

The social, economic, ecological, and physical environments are under unprecedented threat on a local, national, regional, and international level due to climate change. Collaboration at many levels is necessary to address this danger in order to achieve sustainable development, end poverty, and respond to climate change globally (Chen et al., 2018). In addition to the extremes in temperature, exposure and sensitivity of natural and human systems also contribute to the repercussions of climate change and the probability of disasters. Not only do the documented changes in climatic extremes show the effects of human-caused climate change, but they also originate from inherent climate variability. Changes in exposure and susceptibility are shaped by a combination of climatic and non-climatic factors (IPCC, 2012).

The frequency and severity of extreme weather events, including heat waves, heavy precipitation, droughts, and more, have been steadily increasing. The ecology and human population have both suffered greatly as a result of these changes. Henceforth, a focus of scientific inquiry into extreme weather and climate occurrences has emerged (Gu & Shi, 2023). The degree to which the intensity of severe temperatures varies from place to place and is largely dependent on how people respond in terms of adaptation and mitigation strategies. Africa's low level of economic development makes it more vulnerable to various changes in extremely high temperatures (Iyakaremye et al., 2021).

Tanzania, on the other hand, is particularly vulnerable to the adverse effects of climate change, which makes it necessary to put adaptation plans into place in order to safeguard development gains and meet developmental objectives. According to earlier studies and reports, extreme weather has been common in many parts of Tanzania, including noticeable seasonal variations in recorded rainfall and temperature patterns (Osima et al., 2018).

At the moment, little is known about how severe temperatures affect most Tanzanians, particularly at the local community level in the majority of the country's regions. In order to plan and carry out a variety of socio-economic activities that are vulnerable to climatic variability and change, it is imperative to understand seasonal patterns in extreme temperatures in the country, expressly during the time where temperature starts being low (Luhunga, 2022). Furthermore, the creation of successful adaptation plans to climate change depends on a knowledge of these patterns. This study's goal is to investigate the patterns of extreme temperature indices in Tanzania from June to August, taking into account both temporal and spatial dimensions.

2. Data and Methodology

2.1. Study Area

The research site lies in East Africa, more precisely between latitudes 1˚ and 12˚S and longitudes 29˚ and 41˚E (see **Figure 1**). This nation borders the Democratic Republic of the Congo, Burundi, Rwanda, and Zambia to the west, Malawi, Zambia, and Mozambique to the southwest, Kenya, and Uganda to the north, and the Indian Ocean to the east. The nation's complex topography is responsible for the region's diverse climate. The center region, the northeastern highlands, Pemba and Unguja on the Island of Zanzibar, the north, and the southern coast all exhibit bimodal rainfall patterns (Luhunga et al., 2016). In contrast, the western and southern highlands see unimodal rainfall patterns. The main cause of the various rainfall patterns is the shifting of the Inter-Tropical Convergence Zone (ITCZ) (Borhara et al., 2020). From October to February, this zone crosses Tanzania; from March to May, it moves in the other way. Seasonal rainfall varies greatly throughout the nation; in the wettest months, some locations receive as much as 300 mm of rain every month. Tanzania experiences monthly rainfall that ranges from 50 to 200 mm on average.

Tanzania receives an average of 1837 mm of rainfall year and suffers regional variations in its average annual temperature of 14.4˚C (Luhunga et al., 2016; Borhara et al., 2020). Temperatures are often milder in the western and coastal

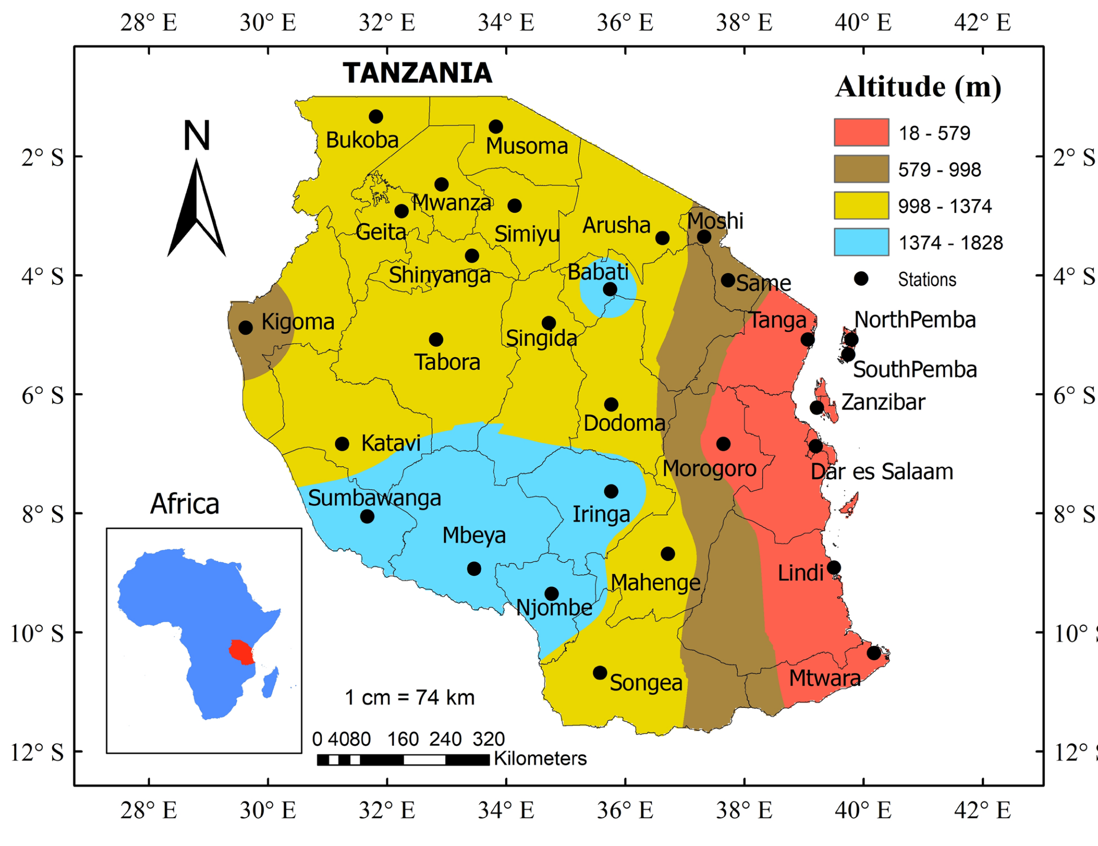

Figure 1. The map showing the stations used in the study area in Tanzania.

regions than in other areas. On the other hand, the low-temperature season begins in May and lasts until August or September. The season with the highest average temperatures nationwide begins in October and lasts until February or March. These localities have average yearly temperatures that range from 9.6˚C to 22˚C to 19.1˚C - 30.7˚C, respectively, at their lowest and highest points.

2.2. Data Source

The total of 29 stations in the country were selected for this study as shown in Table 1 and the gridded data representing daily minimum and maximum temperatures, with a resolution of 0.5˚ × 0.5˚, were acquired from National Oceanic and Atmospheric Administration (NOAA) that can be accessed from https://psl.noaa.gov/data/gridded/data.cpc.globaltemp.html. The data's time span is refreshed on a daily basis, covering from 1979 to present. Any missing data points within this period are marked with a value of −9.96921e+36f.

2.3. Methodology

2.3.1. Quality Control

Every single observation in a series is subjected to quality control (QC) protocols. For both the blended and non-blended station series, these processes are carried out independently. There are three QC flags in use at the moment: Flag = 0 means "valid", Flag = 1 means "suspect", and Flag = 9 means "missing". The following requirements must be met by each component of the daily minimum temperature (TN) and daily maximum temperature (TX): it must be greater

Table 1. The list of 29 stations used in the study area showing geographical coordinates and altitude.

No.	Stations	Longitude (E)	Latitude (S)	Altitude (m)	No.	Stations	Longitude (E)	Latitude (S)	Altitude (m)
1	Arusha	36.63	3.37	1372	15	Mtwara	40.18	10.35	113
2	Babati	35.75	4.23	1551	16	Musoma	33.83	1.5	1147
3	Bukoba	31.82	1.33	1144	17	Mwanza	32.92	2.47	1140
4	Dar es Salaam	39.2	6.87	53	18	Njombe	34.77	9.35	1821
5	Dodoma	35.77	6.17	1120	19	NorthPemba	39.8	5.08	46
6	Geita	32.25	2.92	1224	20	Same	37.73	4.08	860
7	Iringa	35.77	7.63	1721	21	Shinyanga	33.43	3.67	1202
8	Katavi	31.25	6.83	1116	22	Simiyu	34.15	2.83	1119
9	Kigoma	29.63	4.88	822	23	Singida	34.72	4.8	1260
10	Lindi	39.51	8.91	317	24	Songea	35.58	10.68	1036
11	Mahenge	36.72	8.68	1040	25	South Pemba	39.75	5.33	46
12	Mbeya	33.47	8.93	1758	26	Sumbawanga	31.67	8.05	1829
13	Morogoro	37.65	6.83	526	27	Tabora	32.83	5.08	1182
14	Moshi	37.33	3.35	813	28	Tanga	39.07	5.08	49
					29	Zanzibar	39.22	6.22	18

than −90.0˚C and less than 60.0˚C; it must also surpass or equal the daily minimum or maximum temperature (if it exists), it must be less than the long-term average daily maximum temperature for that calendar day plus five times the standard deviation (calculated for a 5-day window centered on each calendar day over the entire period), it must exceed or be equal to the daily mean temperature (if it exists), it cannot be repetitive (i.e., exactly the same) for five consecutive days, and it must exceed the long-term average daily minimum or maximum temperature for that calendar day minus five times the standard deviation (calculated for a 5-day window centered on each calendar day over the entire period) (Project Team ECA & D, 2021).

2.3.2. The Selected Extreme Indices

In order to quantitatively define temperature extremes in the June to August season over Tanzania, the Expert Team on Climate Change Detection and Indices (ETCCDI) list of 27 temperature and precipitation indices in which 16 indices for temperature and 11 for precipitation, only 8 temperature indices were selected as shown in **Table 2**. The selected indices are apt for explicit climatic conditions found in the study area. The public can view these extreme temperature and precipitation indices from the ETCCDI at http://etccdi.pacificclimate.org/indices.shtml. According to Feng et al. (2018), these indices can be divided into two types depending on their indicators: absolute indicators, including minimum Tmin (TNn), maximum Tmin (TNx), minimum Tmax (TXn), and maximum Tmax (TXx). TN10p, TN90p, TX10p, and TX90p are the percentile-based indicators that show how frequently chilly nights, warm nights, and warm days occur.

The study comprises a seasonal trend analysis conducted annually from June to August. The European Climate Assessment & Dataset project (ECA&D) is utilized to calculate climatic indices in accordance with the guidelines provided by ETCCDI. Every index and aggregate period has its trend calculated; in order to perform a trend analysis, at least 70% of the values within a period must contain valid index data, with no missing data (Project Team ECA & D, 2021). The method was also employed in the work of (Ndabagenga et al., 2023).

Table 2. The 8 extreme temperature indices as defined by ETCCDI.

Indices	Indicator name	Index definition	UNITS
TXx	Max T_{max}	The maximum value of daily maximum temperature per season	˚C
TXn	Min T_{max}	The minimum value of daily maximum temperature per season	˚C
TNx	Max T_{min}	The maximum value of daily minimum temperature per season	˚C
TNn	Min T_{min}	The minimum value of daily minimum temperature per season	˚C
TN10p	Cold nights	Percentage of days when daily minimum temperature < 10th percentile in a season	Days
TN90p	Warm nights	Percentage of days when daily minimum temperature > 90th percentile in a season	Days
TX10p	Cold days	Percentage of days when daily maximum temperature < 10th percentile in a season	Days
TX90p	Warm days	Percentage of days when daily maximum temperature > 90th percentile in a season	Days

2.3.3. Mann-Kendall (MK) Test

In the current work, the Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975) was taken to assess the presence of trends in extreme climatic indices. This non-parametric test relies on relative rankings within a specified time range to determine the existence of a trend. The Mann-Kendall test statistic is computed as follows:

$$S=\sum_{i=1}^{n}\sum_{j=i+1}^{n} sign\left(x_j-x_i\right), sign\left(x_j-x_i\right)\begin{Bmatrix} 1 if x_j-x_i>0 \\ 0 if x_j-x_i=0 \\ -1 if x_j-x_i<0 \end{Bmatrix} \quad (1)$$

A positive S value signifies an ascending trend, whereas a negative value denotes a descending trend. The Z value is determined by calculating the variance of the temperature. The computation of the variance (S) is as follows:

$$\operatorname{var}(s)=\frac{1}{18}\left[n(n-1)(2n+5)-\sum_{i=1}^{m} t_i\left(t_i-1\right)\left(2t_i+5\right)\right] \quad (2)$$

A tied group (m) refers to a collection of temperature data points sharing the same value when the sample size is greater than 10 ($n > 10$) and the t_i is the number of data points in the i^{th} tied group. The standard Z test statistic is determined using the following equation:

$$z=\frac{S\pm 1}{\operatorname{Var}(s)^{1/2}} \quad (3)$$

This equation takes $S - 1$ if $S > 0$, $S + 1$ if $S < 0$, and Z is 0 if $S = 0$. A positive value of Z signifies an upward trend. Otherwise, it shows a descending trend.

2.3.4. Sen's Slope Estimator

The Sen's slope (Sen, 1968) estimator was utilized to find the extent of the trends in temperature extremes. This method assumes a linear trend, providing a quantification of the temporal change. Sen's Slope offers an advantage over linear regression as it is unaffected by the presence of outliers and data errors. The equation for Sen's Slope, considering N data sample pairs, is expressed as follows:

$$Q_i=\frac{\left(x_j-x_i\right)}{j-i}, i=1,2,\cdots,N \quad (4)$$

The data values at times j and i (where $j > i$) are represented by x_j and x_i, respectively. In a time series with n values of x_j, the total number of slope estimates N is given by $N = n(n - 1)/2$.

3. Results and Discussion

3.1. Absolute Extreme Temperature Changes

3.1.1. Trends of Extreme Warm Days and Nights

The eastern, northeastern, southwestern highlands, western portion, places surrounding Lake Victoria Basin, northern part, and southern parts have all shown a considerable increase in extreme warm day trends, as illustrated in **Figure 2(a)**, at a rate of 0.016˚C to 0.048˚C. The statistically significant rise has been observed at a rate of 0.02˚C - 0.04˚C in the eastern, northeastern, and northern regions in the analysis of exceptionally warm nights (Figure 2(c)). Significant drops between 0.02˚C and 0.06˚C has been seen in the western, northwest, and southern regions.

3.1.2. Trends of Extreme Cold Days and Nights

The extreme cold days trends have also been observed in the country in which the significant increase is depicted at the rate of 0.00˚C - 0.08˚C in eastern, northeastern, southwest highlands, southern part, western areas and around Lake Victoria Basin. The statistically significant decrease has been seen in few areas of Sumbawanga region at the rate of 0.04˚C - 0.12˚C (Figure 2(b)). In the meantime, the extreme cold nights have been observed with a statistically significant increase in the rate of 0.045˚C - 0.075˚C in the areas of southwestern highlands, eastern parts, Lake Victoria Basin in Bukoba region and Musoma region. In the central, western and southern parts increase at the rate of 0.030˚C - 0.045˚C and they are statistically significant. The statistically significant decrease is seen in the areas of Babati, Arusha and Moshi at the rate of 0.015˚C - 0.030˚C (Figure 2(d)). Generally, the analysis to this absolute extreme temperature during JJA season there is an increase of coldness during the day and nights compared with hotness during days and nights.

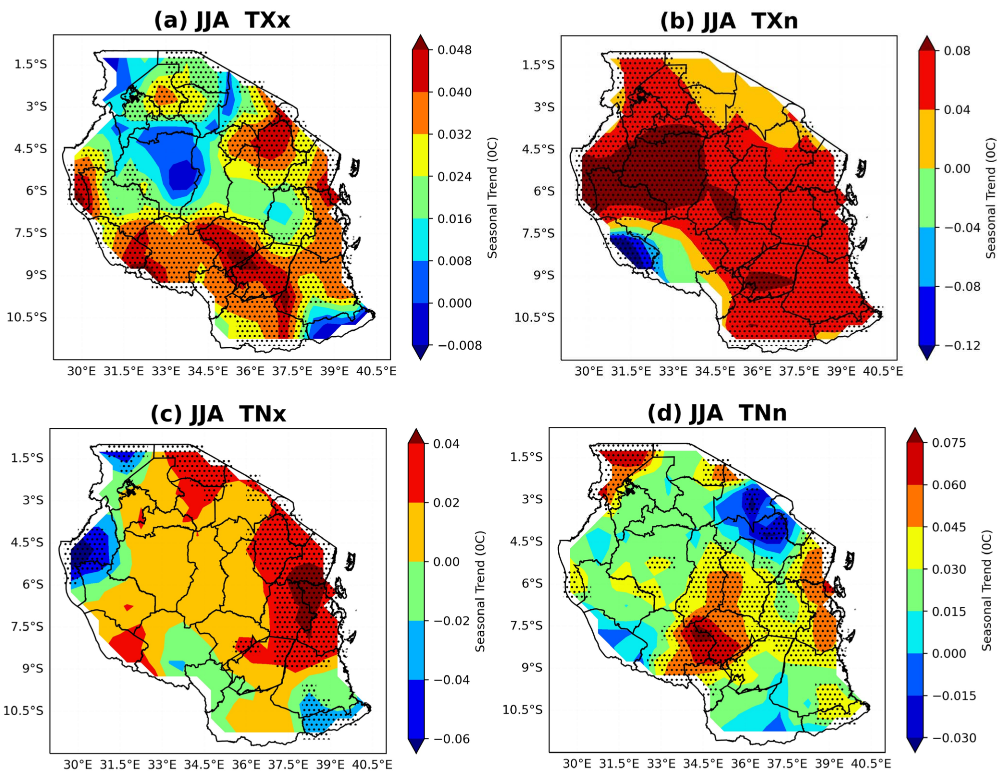

Figure 2. Spatio pattern trends of June to August season over Tanzania during 1982-2022 for absolute extreme temperature showing extreme warm days (a), extreme cold days (b), extreme warm nights (c) and extreme cold nights (d). The dotted areas are significant at 0.05 significance level in accordance with student's t-test.

3.1.3. Temporal Changes of Absolute Extreme Temperature

Figure 3(a)-(d) depicts the temporal changes in the regionally averaged June-August season for each year of severe temperature events in Tanzania from 1982 to 2022. Figure 3(a) shows a substantial increase in extreme warm days (TXx) at a rate of 0.01677˚C per year during the season, while Figure 3(c) shows no statistically significant increase in extreme warm nights (TXn) at a rate of 0.014˚C per year during the season. The extreme cold days (TNx) increased at the rate of 0.00594˚C in the season every year with no statistically significant (Figure 3(b)). In the meantime, the extreme cold nights (TNn) increased at the rate of 0.00973˚C in the season every year with no statistically significant (Figure 3(d)). Generally, in all absolute indices there is an interannual variation during the season of JJA, and in particularly the extreme warm indices which shows consistent increase from the year 2002 to 2022.

3.2. Percentile Extreme Temperature Changes during June to August Season

3.2.1. Trends on Warm Days and Nights

During the analysis of these indices, it was disclosed that the warm days (TX90p), had significantly increased in the eastern, northeastern, southern parts, western areas and around Lake Victoria Basin at a rate of 0.125 - 0.150 days in a

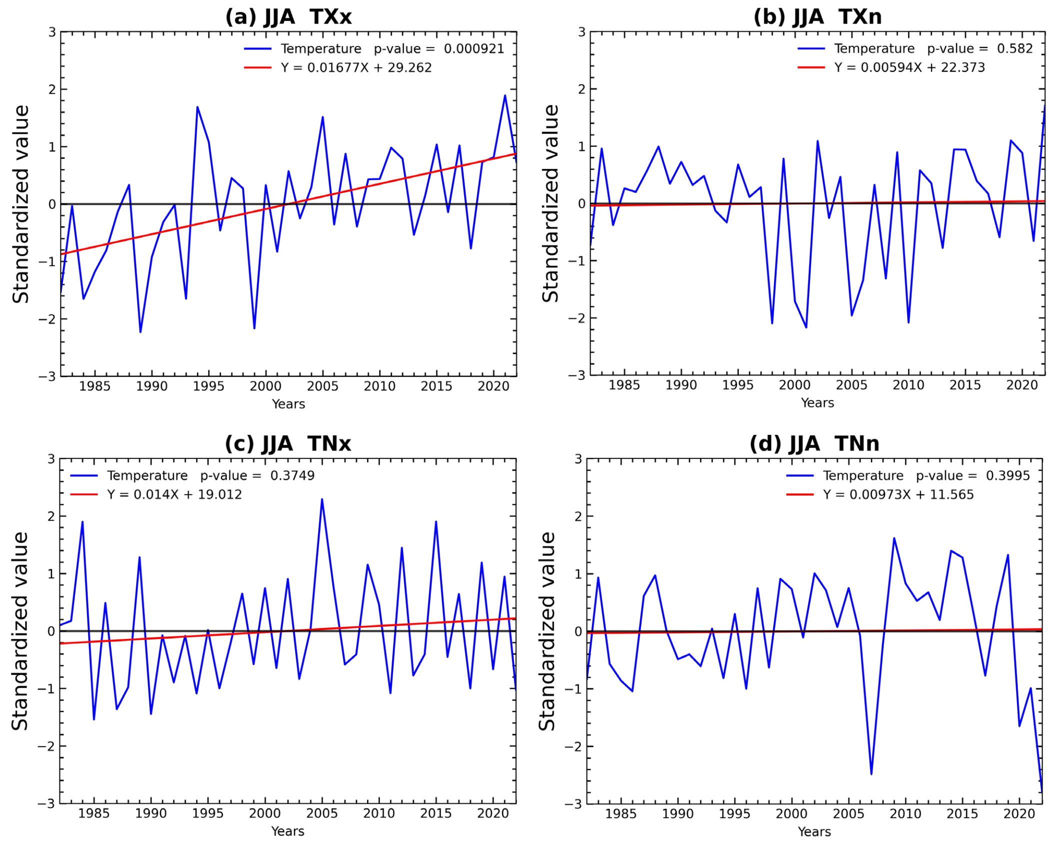

Figure 3. Temporal series of standardized value for the June to August season of absolute extreme temperature indices over the study area during the period 1982-2022.

season in each year. In the areas of central, some parts of Lake Victoria Basin, southwestern highlands, few areas of western country and some northern parts had a statistically significant increase at the rate of 0.050 - 0.125 days in a season in each year (**Figure 4(a)**).

The warm nights (TN90p) had a statistically significant increase at the rate of 0.09 - 0.15 days in a season in each year in the eastern, northeastern parts, and Musoma region. In the areas of central, some parts of Lake Victoria Basin and few areas of southwestern parts had a statistically significant increase at the rate of 0.06 - 0.09 days in a season in each year. Slight significant increase has been seen in some few areas of Southern parts especially in Songea region, southwestern highlands and the region of Bukoba, Singida and Shinyanga at the rate of 0.03 - 0.09 days in a season in each year. A statistically significant decrease has been observed in the western parts of the country at the rate of 0.03 - 0.6 days in a season in each year (**Figure 4(c)**).

3.2.2. Trends on Cold Days and Nights

According to the data, the number of cold days has decreased nationwide at a pace of 0.04 to 0.12 days per season on an annual basis. A statistically significant increase at the rate of 0.04 to 0.16 days in a season per year has only been observed in a few numbers of places of the southwestern highlands, mainly in the

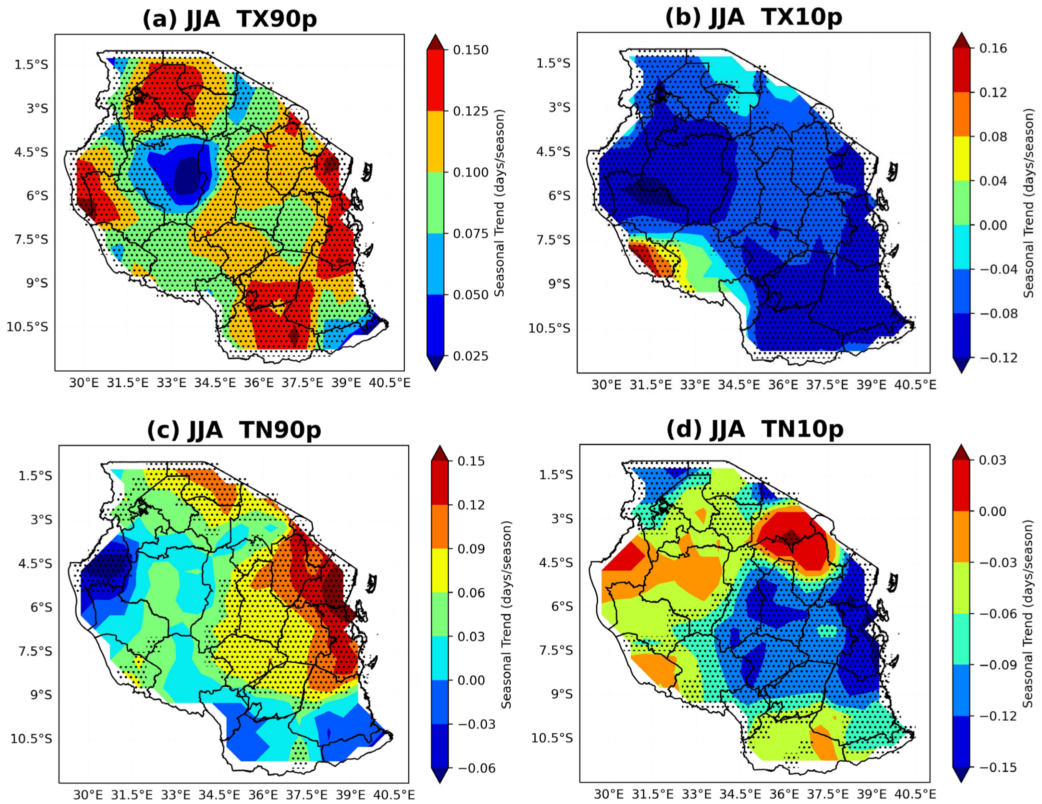

Figure 4. Spatio pattern trends of extreme temperature during the June to August season over Tanzania for warm days (a), cold days (b), warm nights (c) and cold nights (d) from 1982-2022. The dotted areas are significant at 0.05 significance level in accordance with student's t-test.

Mbeya region and the western parts of the Sumbawanga region (**Figure 4(b)**). In most parts of the country, the number of cold nights has significantly decreased throughout the June-August season. At a rate of 0.03 to 0.15 days per season every year, a statistically significant decline has been observed in the eastern, northeastern, Lake Victoria Basin, southern, southwestern highlands, and central regions of the country (**Figure 4(d)**).

3.2.3. Temporal Changes during June to August Season of the Percentile Extreme Temperature

Figure 5(a)-(d) depicts the temporal variations in Tanzania's regionally averaged June–August season for each year of severe temperature events from 1982 to 2022. The warm days (TX90p) in **Figure 5(a)** exhibit interannual fluctuation and a noteworthy rise at a rate of 0.1043 days per season from 1982 to 2022. There is a little increase in warm days from 1982 to 2001, but there is an upward trend from 2002 to 2022. The number of warm nights (TN90p) is also rising significantly, at a pace of 0.0644 days in a season in each year. From 2000 to 2022, the trend shows increasing values, with the small value observed from 1983 to 1999 (**Figure 5(c)**). The variation of cold days in a season observed to decrease significantly at the rate of -0.0335 days in a season in each year and the value was higher from 1982 to 2000 and thereafter the value was slightly small (**Figure 5(b)**). Likewise, cold nights (TN10p) appeared to decrease significantly at the rate of −0.0749 days in a season in each year. The value was higher from 1982 to 2000 and then the decrease had small value to 2022 (**Figure 5(d)**). It is found in this result that the warm days and nights are increasing in which the value of increase in warm days (0.1043 days in a season in each year) are larger than warm nights (0.0644 days in a season in each year) while the decrease rate of cold days (−0.0335 days in a season in each year) was smaller than cold nights (−0.0749 days in a season in each year) which shows that the night cooling was higher than daytime cooling. The overview from the results, it indicates that during JJA season extreme events related to extreme temperatures in the country both significantly increased and decreased with respect to their related indices. The results also demonstrate that the extreme temperature indices during the JJA season have increased significantly in line with the global climate warming expectations.

In comparison, the findings of this study indicate a noticeable increase in warm days and nights, accompanied by a decreasing trend in cold days and nights in the season. Some of the factors that may have contributed to the current seasonal changes include rising greenhouse gas concentrations, which have resulted in overall warming trends, as well as urban settlement development, where human activities and the built environment have occasioned in high temperatures. Moreover, changes in land cover and use practices, such as deforestation and agricultural expansion, have the potential to influence local temperature patterns. Furthermore, the study suggests that anthropogenic influences may contribute to the warming trend observed in extreme daily minimum and

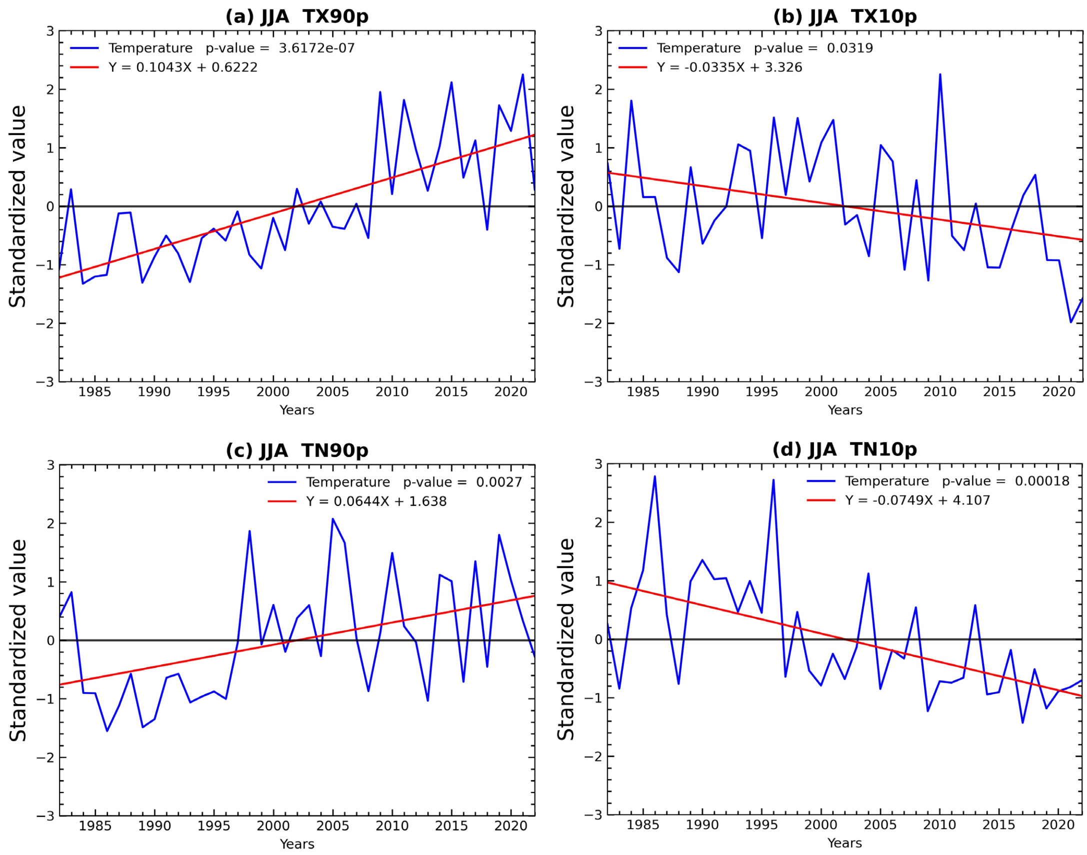

Figure 5. Temporal series of standardized value for the June to August season of percentile extreme temperature indices over the study area during the period 1982-2022.

maximum temperatures globally (IPCC, 2012), with Tanzania potentially affected, as revealed in the current research. The overall results of this study reflect patterns observed in various regions worldwide, where warm days and nights are on the rise while cold days and nights are diminishing, as documented by (Hartman et al., 2013) and (Tong et al., 2019).

4. Conclusion

The research analyzed the trends of variation of extreme temperature during June to August season for the period of 1982-2022 over Tanzania by selecting absolute extreme temperature indicators and percentile extreme temperature. This research focused on 8 extreme temperature indices, and the ECA&D conducted the seasonal computation of these indices using the established ETCCDI procedures. The main outcomes of this investigation can be briefed as:

1) The analysis to the absolute extreme temperature during JJA season showed an increase of coldness during days (TXn) and nights (TNn) compared with hotness during days (TXx) and nights (TNx). The indices depicted an interannual variation during the season of JJA.

2) The percentile extreme temperatures demonstrated the significant increasing warm days (TX90p) and nights (TN90p) while significant decreasing was

seen to cold days (TX10p) and nights (TN10p). Both types of indices exhibit noticeable turning points in their time series.

Future research work should consider analyzing the remaining seasons and delve deeper into understanding the role of human activities in regional climate warming and the association to the atmospheric circulations. This comprehensive investigation can contribute to better prevention and monitoring, providing a more informed basis for decision-making in regional agricultural and animal husbandry production in Tanzania.

Data Availability

The data that support the findings of this study are openly available at the https://psl.noaa.gov/data/gridded/data.cpc.globaltemp.html.

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Conflicts of Interest

The authors have no any conflict of interest to the publication of this work.

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