Ghana Journal of Geography

journal homepage: https://www.ajol.info/index.php/gjg https://journals.ug.edu.gh/index.php/gjg/

Analysis of Rainfall and Temperature Dynamics (1981 to 2021) in Semi-Arid Central Tanzania

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article info

Article history:
Received 27th November 2023
Accepted 15th January 2024

Keywords:
Climate Change,
Climate variability,
rainfall,
temperature,
Semi-arid

abstract

This study investigates the impact of climate change on rainfall and temperature dynamics in Bahi and Mpwapwa Districts , Dodoma Region, Tanzania , over 41 years (1981 – 2021). The study used historical temperature and precipitation data from the Tanzania Meteorological Authority (TMA). The dataset was analyzed using linear regression and the Mann -Kendall trend test using MS Excel (2010) and SPSS V20. The results indicate slight increases in annual rainfall in Mpwapwa (3.717mm) and Bahi (2.743mm). However, mean decadal precipitation analysis reveals that Mpwapwa experienced a decrease in rainfall during the first three decades , followed by a significant increase in the most recent ten years . Conversely, the amount of rainfall in Bahi remained relatively consistent throughout, except for the last ten years, when there was an increase in precipitation compared to the earlier decade . However , the Mpwapwa district is observing an increase in the number of rainy days, whereas Bahi is experiencing a decrease. Additionally , both districts have encountered a notable rise in both minimum and maximum temperatures . These changes , particularly the increase in temperature and fluctuating rainfall , significantly impact agro-pastoral communities in these semi-arid regions . The study underscores the need for these communities to implement stronger adaptation strategies to mitigate the adverse effects of rising temperatures and changing rainfall patterns.

Introduction

Globally , the rise in average surface temperature and the shifting distribution of precipitation across space are the primary factors behind the recent shifts in global climate patterns which have increased the frequency of extreme weather events such as droughts and floods (IPCC, 2014). These changes have adversely affected crop productivity and livestock production, particularly in regions that rely heavily on agro-pastoral systems. Several studies conducted globally (Asare-Nuamah & Botchway, 2019; Derbile et al., 2022; Kumar & Jain, 2011; Mkonda & He, 2017; Yanda & Bronkhorst, 2011) have emphasised the increasing difficulties presented by climate change, with changing patterns of rainfall and increasing temperatures being the main areas of concern. In arid and semi-arid regions, cumulative consequences of climate change and variability put pressure on smallholder agro-pastoral systems due to a low adaptive capacity, such as a lack of financial, institutional, and technological capacity (Mung'ong 'o et al., 2019; Sewando et al ., 2016). The African continent is particularly susceptible to the impacts of climate change and variability. This vulnerability is primarily attributed to its significant reliance on rain-fed agriculture and pastoralism , particularly in regions characterised by arid and semi -arid conditions (Huang et al., 2016). According to Yanda et al. (2022), the continent has witnessed a notable increase in temperatures , changes in rainfall patterns, prolonged periods of drought, and an increase in the frequency of extreme weather events.

The changes have resulted in diminished agricultural productivity , heightened vulnerability to food scarcity , livestock depletion , and the forced relocation of communities (Perfect & Majule, 2010). Arid and semi-arid lands (ASALs), characterized by their lower level of development are particularly vulnerable to various shocks and stresses , including the effects of climate change (Mabhuye et al., 2015). The East Africa is characterised as a geographical area highly vulnerable to climate change , leading to significant consequences for agro - pastoral systems.

In Tanzania , recent studies have expanded our understanding of the climatic patterns in semi -arid regions globally by integrating up-to-date temperature and precipitation data. Prior studies conducted by Matata et al. (2019), Myeya (2021a), and Sewando et al. (2016b) have provided insights into the impact of significant climatic factors in semi -arid Tanzania . These studies indicate a pattern of declining precipitation and rising temperatures over a period of time. However , there is still a gap in conducting a comprehensive analysis of seasonal fluctuations that does not adequately address the persistent shifts in precipitation and temperature , especially during the period from 1981 to 2021. This discrepancy greatly impedes a comprehensive comprehension of the impact of climate change on agriculture, livestock , and ecosystems in the semi - arid regions of Central Tanzania. By adopting a comprehensive approach, our research outcomes become more pertinent and practical, thereby enriching the collective comprehension of climate dynamics at both regional and global levels

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http://dx.doi.org/10.4314/gjg.v16i2.9

Material and methods

Description of the Study Area

Bahi and Mpwapwa District Councils are among the eight local government authorities of the Dodoma region. Bahi district occupies an area of 5,948 square kilometres. In contrast, agricultural, livestock keeping, small-scale mining, residential, commercial, small-scale industries, small enterprises, and forest reserves are prominent land uses in the district (URT, 2017a). Mpwapwa district has a total surface area of 7,379 sq. km. of which most of the site is predominantly with spontaneous mountain chains, especially in the southern and western parts with steep hills, ridges, valleys, and escarpments (URT, 2017b).

2.2 The climate of the study area

Typically, the Dodoma region experiences a dry savanna environment characterized by a prolonged dry season lasting from late April to early December, followed by a short wet season during the remaining months. The temperatures in the region vary based on altitude, with average maximum and minimum temperatures from October to December being 31°C and 18°C (degrees Celsius), respectively. In the cool, dry season of June to August, the temperatures range from 27°C to 28°C for maximum and 10°C to 11°C for minimum temperatures (URT, 2017b, 2017a). The average annual rainfall in Dodoma is around 570mm, with approximately 85% of this precipitation occurring between December and March. In general, rainfall in the Dodoma region is low and unpredictable in terms of both frequency and amount, presenting challenges for farmers, particularly during January, the prime planting season for most crops (URT, 2007).

2.3 Data collection methods

For this research, weather-related data encompassing a period of 41 years, from 1981 to 2021, were meticulously gathered, focusing specifically on temperature and rainfall metrics. The data sets were acquired from the Tanzania Meteorological Agency (TMA), headquartered in Dar es Salaam, which is recognized for its authoritative role in maintaining and providing access to such climatological records.

2.4 Data analysis

The study employed linear regression analysis to examine the trend and magnitude of change in rainfall and temperature for the past 41 years (1981-2021) in the study area. Specifically, the analysis involved fitting a linear regression model to the rainfall and temperature data collected from the Bahi and Mpwapwa stations. Linear regression is well-suited for detecting trends in time series data, making it a suitable choice for analyzing the continuous and sequential nature of annual rainfall and temperature observations(Chepkoech et al., 2018).

The linear regression model for rainfall was formulated as

$y = a + bx$……………... (1)

where *y* represents the annual rainfall, *x* represents the year, a means the intercept, and b represents the slope coefficient—the model aimed to estimate the relationship between the year and the corresponding rainfall values. The coefficient of determination (R-square) was used to assess the goodness of fit of the linear regression model, indicating the proportion of the variance in rainfall that can be explained by the year.

Similarly, a linear regression model was constructed for temperature as

$y = a + bx$………………..(2)

y represents the annual temperature, x represents the year, a represents the intercept, and b represents the slope coefficient. The model aimed to estimate the relationship between the year and the corresponding temperature values. The coefficient of determination (R-square) was used to evaluate the adequacy of the linear regression model, indicating the proportion of the variance in temperature that can be explained by the year.

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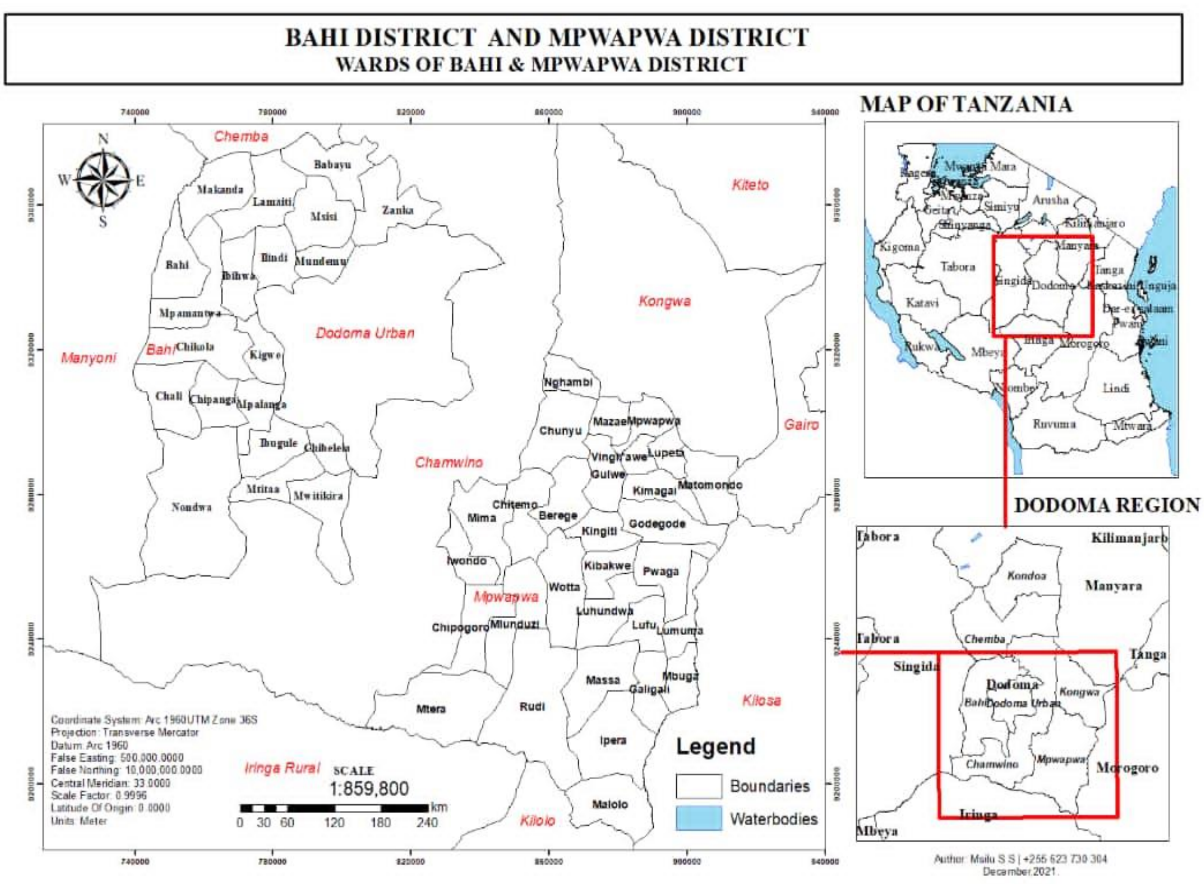

Figure 1: Location of the study areas

By utilizing linear regression analysis, the study aimed to assess the trends in rainfall and temperature over the study period and determine the magnitude of change in these climatic variables. The trend line derived from the regression analysis provided insights into the direction and intensity of the observed changes. The coefficients and statistical significance of the regression models aided in quantifying the relationship between the year and the respective climatic variable.

Overall, applying linear regression analysis and determining R-square and trend lines enabled the study to comprehensively evaluate the trend and magnitude of change in rainfall and temperature at the Bahi and Mpwapwa stations in the study area.

The methodological approach employed in this study includes applying the Mann-Kendall (MK) trend test and Sen's slope estimate to analyse the time series data. The Mann-Kendall test is a non-parametric statistical test utilised for trend detection, while Sen's slope estimate calculates the magnitude of the trend. The appropriateness of data for Mann-Kendall analysis and the understanding of outcomes are derived from case studies that have employed a comparable methodology(Rahman et al., 2019). The formulas used in these calculations are as follows:

For Mann-Kendall Trend (Q):

$Q = \Sigma \, \mathrm{sgn}(x_j - x_i)$……………………3

Where x_j and x_i represent data values at times j and i, respectively, with $j > i$, the function $\mathrm{sgn}(x_j - x_i)$ is the signum function, yielding 1 for positive differences, -1 for negative differences, and 0 for ties. Q measures the strength and direction of the trend.

Sen's Slope Estimate (B):

$B = (x_j - x_i) / (t_j - t_i)$…………………..4

X_j and x_i are data values, and tj and ti are the corresponding time points. B represents the average rate of change over time and provides an estimation of the trend magnitude.

The onset of rainfall was defined as the first date after a specified dry period where a cumulative threshold of rainfall was reached, translated into the Julian date (see annexe 1). The cessation of rainfall was identified as the last date of recorded rainfall before the onset of a specified dry period, also translated into the Julian date.

Results and Discussion

Rainfall Trends in Mpwapwa and Bahi

Total annual rainfall

Linear regression models were used to comprehend the variations in precipitation over the years. Figure 2 shows the results that in Mpwapwa, there is a slight yearly rise in rainfall, as shown by the regression equation y = 3.7171x + 640.48, where 'y' represents the total amount of rainfall and 'x' represents the number of years. The model's coefficient of determination, R^2, is 0.0876. This indicates that the linear trend accounts for only a small portion (approximately 8.76%) of the total annual rainfall variation.

Similarly, the regression equation for Bahi, y=2.7429x+502.31, indicates a slight positive correlation between rainfall and time. Nevertheless, the R-squared value of 0.0742 for Bahi suggests a model fit that is even poorer than that of Mpwapwa. This value indicates that the model accounts for only approximately 7.42% of the variability in the rainfall data. These findings indicate that there is a small increase in rainfall amounts over the 41-year period for both locations. However, the linear regression models have limited ability to accurately predict this trend. This suggests that other factors and intricate dynamics are likely to have a significant impact on annual rainfall patterns.

Specific periods, such as 1981/82, 1993/94, and 2005/06, recorded declines in rainfall, likely due to the effects of global warming and cooling. In contrast, other periods like 1989/90, 1997/98, and more recent years from 2014 to 2021 witnessed significant increases in rainfall. These inconsistencies underscore the complex and variable nature of climate trends in these areas.

Similar findings have emerged from other semi-arid regions in Tanzania. For instance, trend analysis from the Dodoma station (Myeya 2021), covering the period from 1961 to 2013, revealed an upward yet statistically insignificant trend in temperature and rainfall, with a marginal increase of 0.3% in rainfall over 53 years. Similarly, predictions from Iyamuremye et al. (2019) indicate a future rise in maximum rainfall in Dodoma. These trends are not uniform and are marked by periods of increase and decrease influenced by global climatic patterns.

An additional analysis of rainfall was conducted for the Mpwapwa and Bahi districts (table 1) in order to ascertain descriptive statistics for rainfall across all stations. The rainfall data spanning 41 years for the districts of Mpwapwa and Bahi in Tanzania reveals clear and discernible climatic patterns. The annual precipitation in Bahi ranged from 328mm to 998mm, with an average of about 559.91mm and a standard deviation of 120.645, indicating a moderate level of variability around the mean. In contrast, Mpwapwa showed a wider spectrum, with yearly rainfall ranging from 412mm to 1309mm and a higher mean of 718.54mm. The higher standard deviation of 150.480 in Mpwapwa implies greater fluctuations, indicating a more variable and potentially unpredictable rainfall pattern compared to Bahi. These statistics demonstrate both the natural variation in semi-arid climates and the unique climatic characteristics of two neighbouring districts.

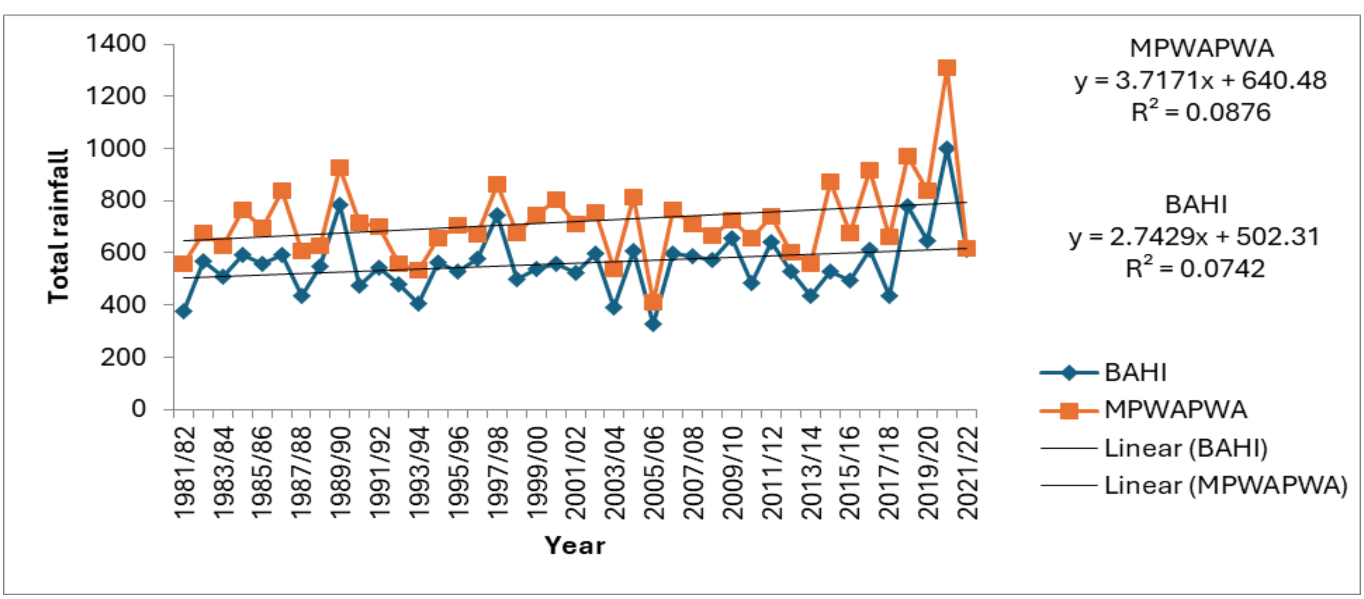

Figure 2: Mpwapwa and Bahi total rainfall in mm from 1981 to 2021.

Computation based on TMA 2022

A similar study conducted in Dodoma, Mpwapwa and Bahi between 1961–2013 by Myeya (2021a) found significant rainfall differences.
Consistently, Mpwapwa recorded higher maximum and minimum rainfall compared to Bahi and Dodoma. Bahi appears to be more susceptible to rainfall variations compared to the other two districts in Dodoma.

3.1.2 Mean Decadal Rainfall of Mpwapwa and Bahi

The decadal rainfall in the Mpwapwa district (Figure 3) shows a decreasing trend in annual rainfall over the past three decades (1991-2021), except for the last decade (2011-2021), when rain increased significantly. The average annual rainfall in Mpwapwa decreased from 702.748 mm to 691.432 mm between 1981 and 2001. It further declined to 675.479 mm from 2001 to 2010 before increasing to 796.70 mm from 2011 to 2021. The rainfall in Bahi district has shown a slight increase from 543.843 mm in 1981-1990 to 610.397 mm in 2011-2021. This trend suggests that the district is less susceptible to precipitation changes compared to Mpwapwa.
Semi-arid regions have substantial decadal rainfall variation (Huang et al., 2016). However, other scholars like Myeya (2021a) reported the same decadal fluctuations of rainfall; for example, during the first decade (1961-1970), Bahi and Mpwapwa stations received above-average rainfall, while Dodoma received less. In the following decade, rainfall decreased at all stations, with Mpwapwa having the most significant decrease. In the third decade (1981-1990), all three stations experienced above-average rainfall. However, in the fourth decade (1991-2000), both Bahi and Mpwapwa witnessed a decrease in rainfall. Mpwapwa recorded the lowest rainfall among the three stations in the last decade (2001-2010).

3.1.3 Average Monthly Rainfall

Bahi and Mpwapwa experience a single rainfall season from October to May, with December and January typically receiving the highest rainfall. According to Figure 4, Bahi receives 134.3mm of rainfall in December and 176.7mm in January, while Mpwapwa receives 138mm and 178.1mm respectively. The concentrated rainfall season between October and May, particularly with peak rainfall in December and January, may significantly impact agro-pastoral systems. The precipitation patterns during this period exhibits high variability. Furthermore, the decrease in rainfall in February, followed by an increase in March, has the potential to disrupt agricultural activities and water resource management.
This rainfall variability can affect agro-pastoral productivity and require careful adaptation strategies. These findings are consistent with semi-arid Dodoma studies. Mung'ong'o et al., (2019) 1986–2016, (Myeya, 2021a) 1961–2013, (Myeya, 2021b) 1961–2013, (Gosbert et al., 2022) 1990–2020.

Table 1:Descriptive Statistics of Rainfall in Mpwapwa and Bahi from 1981 to 2021

	N	Minimum	Maximum	Mean	Std. Deviation
Bahi	41	328	998	559.91	120.645
Mpwapwa	41	412	1309	718.54	150.480

Source: Computation based on TMA 2022

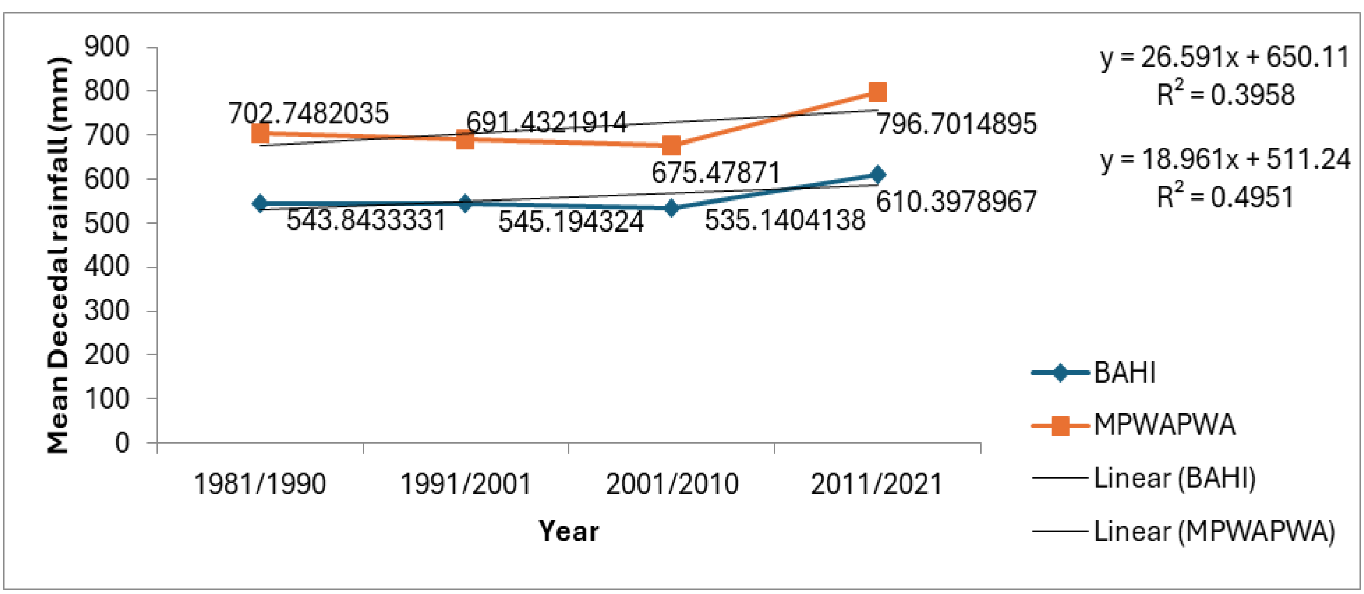

Figure 3: Mean decadal precipitation in mm for Mpwapwa and Bahi districts 1981-2021.
Source: Computation based on TMA 2022

The Mann-Kendall test identified trends in Bahi District, while Sen's slope estimate determined their magnitude and direction. Specifically, the December results reveal a statistically significant negative trend at a 5% significance level. Over 41 years, December rainfall has decreased. March and April show positive trends, with March being statistically significant at 95% confidence. December results for Mpwapwa District show a similar decreasing trend, though not statistically significant. However, January rainfall has increased over the past 41 years and is statistically significant at a 5% significance level. March has the highest 95% confidence level positive trend. Rainfall during crop growth is irregular and unpredictable.

The timing of the first rains, the distribution and duration of rainfall during the growing season, and the effectiveness of each precipitation event determine farming success. February's decreasing trend shows that rainfall decreased during a critical crop-growing period, reducing crop and pasture productivity.

These findings match those (Matata et al., 2019) in Tabora, Tanzania, which shows that December rainfall has steadily decreased. In semi-arid regions, seasonal variability has been observed in rainfall trends during the growing season (Matata et al., 2019; Myeya, 2021a; Sewando, 2016b).

3.1.4 Onset, cessation, and season length in Bahi and Mpwapwa.

The findings from Figure 5 indicate that Bahi experiences a later precipitation onset date (25th Dec) compared to Mpwapwa (22nd Dec). Additionally, Bahi's rainy season typically extends until 04th May, while Mpwapwa's lasts until 08th Apr on average. The duration of the rainy season at Bahi and Mpwapwa stations is crucial information for understanding their respective agro-pastoral systems, as both agriculture and grazing activities rely heavily on the duration and timing of the rainy season.

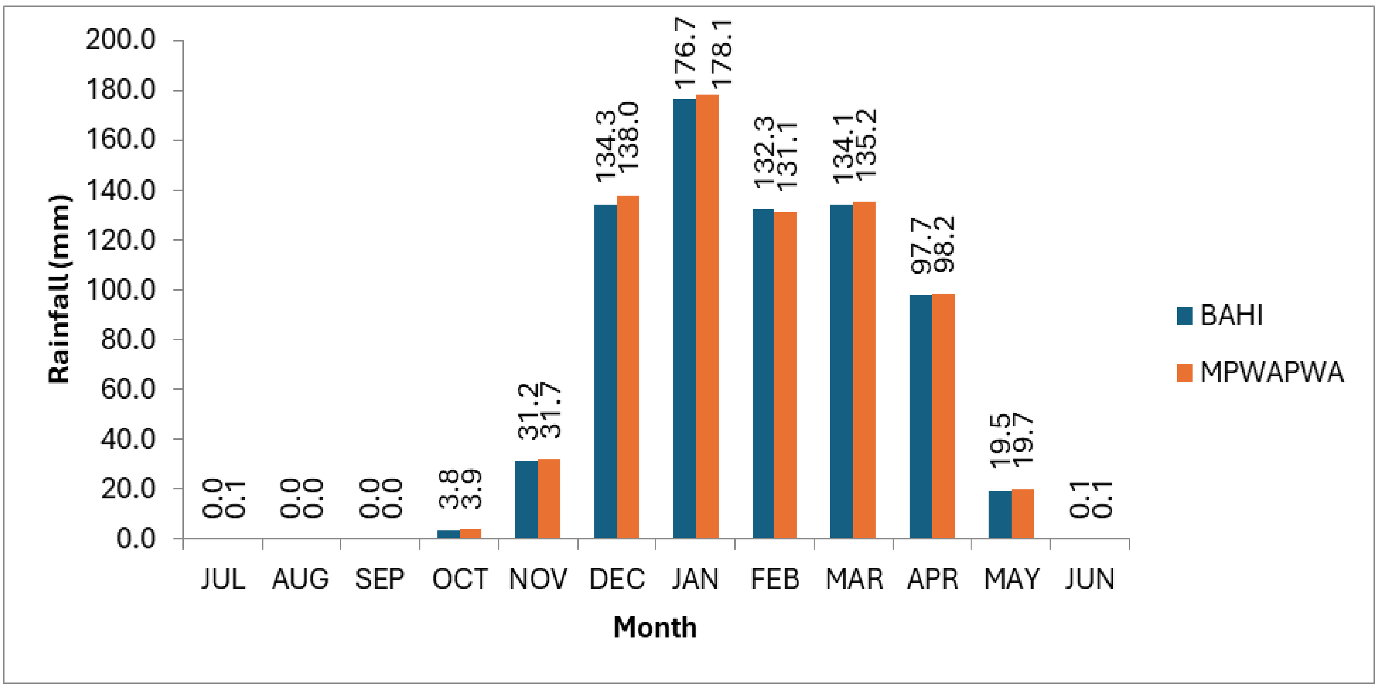

Figure 4: Average monthly rainfall in mm of Mpwampwa and Bahi
Source: Computation based on TMA 2022

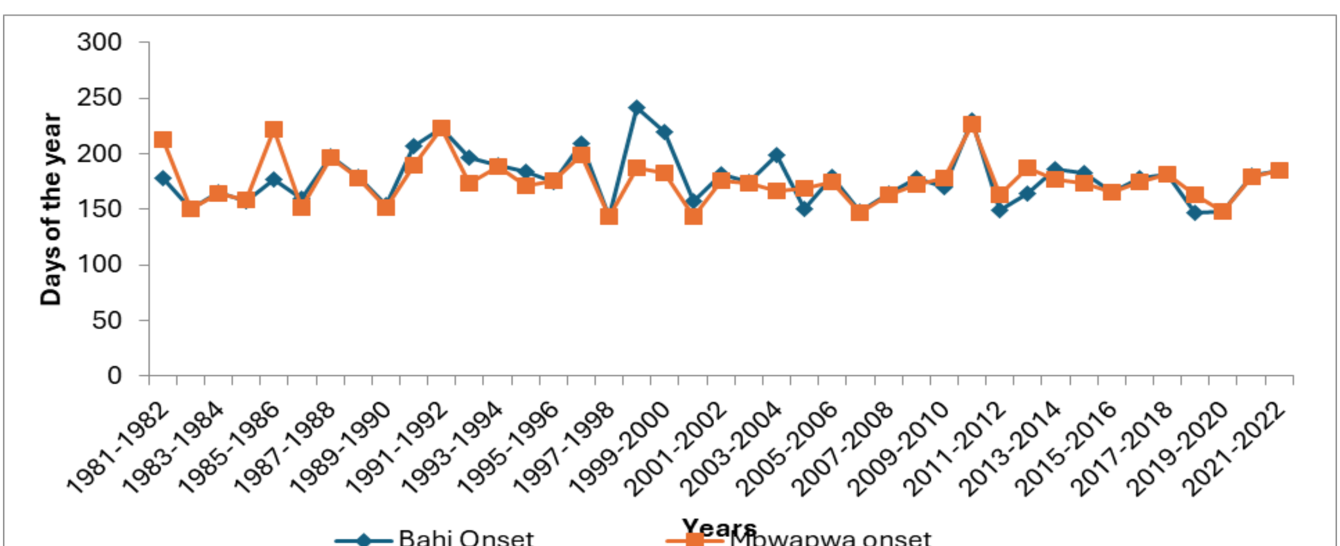

Figure 5 - Rainfall onset day of the year for Bahi and Mpwapwa
Source: Computation based on TMA 2022

According to the study, the rainfall season in Bahi lasts from 69 to 175 days, with an average of 128 days of rainy season. Mpwapwa's rainy season averages 111 days. Both stations' long rainy seasons present opportunities and challenges for the agro-pastoral system. Farmers' planning and management can be hampered by this variability. Drought-tolerant crops or irrigation may be needed due to a shorter rainy season. A more extended rainy season boosts yield and pasture growth, which benefits agriculture and livestock is required.

Mpwapwa has a shorter rainy season than Bahi. Bahi has less annual rainfall than Mpwapwa. Based on 1981–2021 data, Bahi receives 559.9mm of rain annually, and Mpwapwa receives 718.54mm. Mpwapwa's higher rainfall promotes drought-resistant crops, livestock pasture, and semi-arid region water supply. The difference in rainfall between Bahi and Mpwapwa affects agricultural and pastoral activities. Bahi's lower annual rainfall may hinder crop growth and livestock grazing.

Findings (Figure 6) show that Bahi cessation dates range from day 283 (09th Apr on a non-leap year) to day 327 (23rd May), indicating that the rainy season can end anytime from early April to late May. Mpwapwa cessation dates are more consistent, ranging from day 276 (02nd Apr) to day 310 (05th Jun). Most of Mpwapwa's cessation dates are concentrated in early April, suggesting a more stable end to the rainy season than Bahi.

A notable observation is the variability of cessation dates for Bahi, which may suggest greater climatic variability in that region or a difference in geographical and topographical influences affecting weather patterns. In contrast, Mpwapwa's cessation dates show less variability, hinting at a more predictable end to the rainy season in this area.

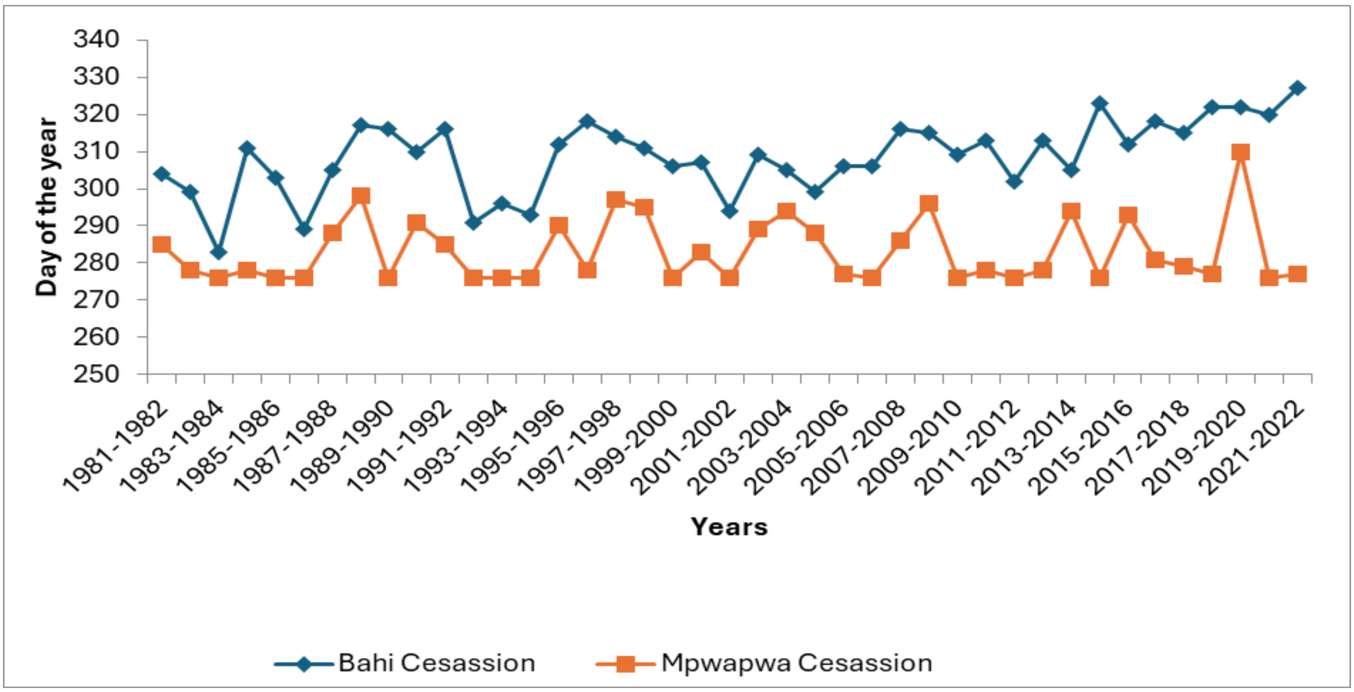

Figure 6: Rainfall cessation day of the year for Bahi and Mpwapwa

Source: Computation based on TMA 2022

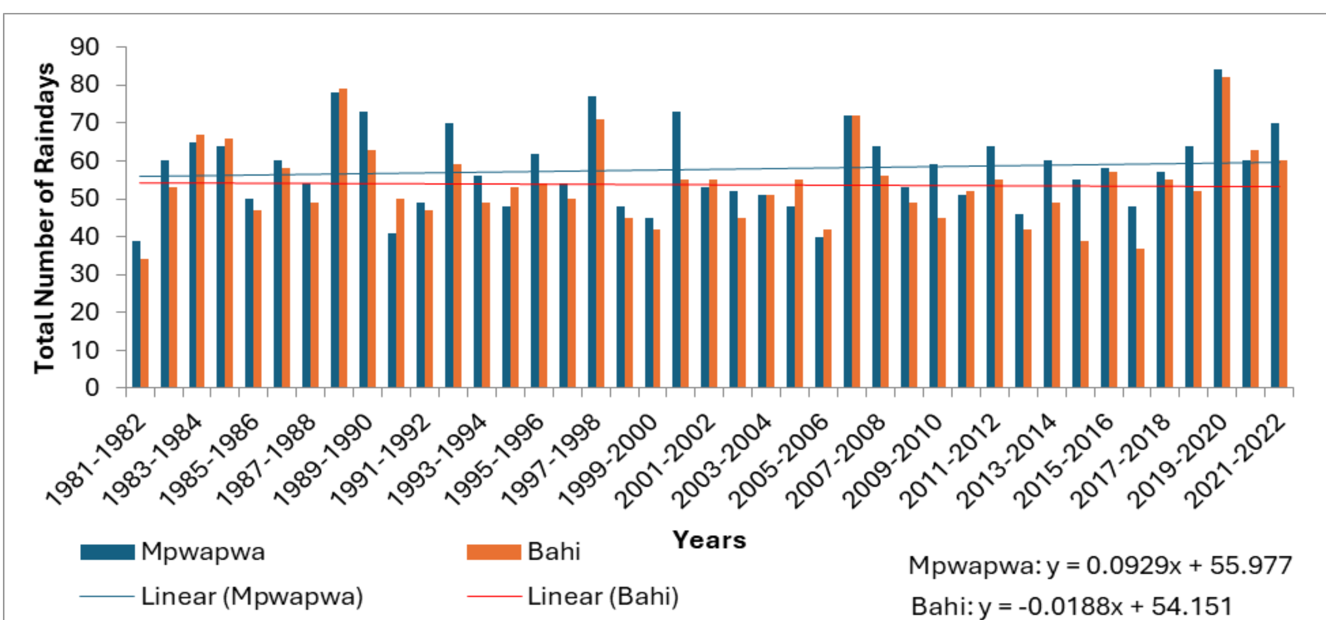

Figure 7: Number of rainy days for Bahi and Mpwapwa from 1981 to 2021

Source: Computation based on TMA 2022

Furthermore, it is noteworthy that in recent years, Bahi's rainy season has consistently ended later, with the latest cessation recorded in 2021-2022. This observation may indicate changing weather patterns attributed to broader climatic shifts.
Similar findings (MacLeod, 2018; Omay et al., 2023) in other East African countries show that the earliest average end dates for the March, April, and May seasons were recorded as 26th Apr, 03rd May, and 17th May in lower eastern and northern Kenya, southeastern Ethiopia, and most of Somalia, respectively. In other semi-arid regions of Tanzania, studies show the onset and cessation were found to be unpredictable (Myeya & Mulungu, 2021).

Number of rainy days in a season

Findings (Figure 7) show that Bahi had an average of 53.76 rainy days per year, ranging from a minimum of 34 days to a maximum of 82 days. This indicates a significant variation in annual rainfall. The standard deviation of 10.52 suggests a moderate level of variability in the annual number of rainy days. Conversely, Mpwapwa experienced an average of 54.37 rainy days per year, ranging from a minimum of 36 to a maximum of 79 days, indicating that it generally received a greater amount of rainfall compared to Bahi. The standard deviation is marginally greater at 10.68, suggesting a comparable degree of annual fluctuation to Bahi. The data for both locations exhibit a significant disparity in the frequency of rainy days, emphasising the fluctuation in annual precipitation patterns.
Upon analysing the data trends, it is evident that both stations display certain years with notably higher or lower frequencies of rainy days, indicating the presence of outlier years or shifts in weather patterns. During the period of 2019-2020, both Bahi and Mpwapwa stations experienced an unusually high number of rainy days. Bahi recorded 82 days of rain, while Mpwapwa recorded 79 days, which is significantly higher than their usual averages. In a similar vein, the initial years, specifically 1981-1982, documented some of the fewest instances of rainy days. These variations could be attributed to overarching climatic factors such as El Niño or La Niña events or the long-term effects of climate change.
According to the linear regression analysis, Mpwapwa shows a positive slope of 0.0929, indicating a gradual upward trend over time. This suggests that, on average, the annual number of rainy days has been increasing by a small amount according to this model. The intercept value of 55.977 represents the model's estimation for the starting year in the dataset, which is 1981. Conversely, Bahi's negative slope of -0.0188 indicates a subtle decline, implying that the frequency of rainy days has been decreasing annually by a minor degree, as indicated by this model.
Numerous studies examining various aspects of rainfall characteristics in the semi-arid regions of central Tanzania have been conducted(Matata et al., 2019; Helena Elias Myeya, 2021; Sewando et al., 2016b). However, there has been a noticeable gap in understanding the specific trends related to the number of rainy days in these areas. Addressing this gap, the present study sheds light on this previously understudied aspect and contributes valuable insights into the changing patterns of rainy days within this region.

Rainfall Extremes in Bahi and Mpwapwa

Findings (Tables 1 and 2) show that on 09th Dec 1996, the Bahi district witnessed its highest recorded rainfall of 47.67 mm, as per data recorded by the Tanzania Meteorological Authority (TMA) from 1981 to 2021. The district experienced a range of extreme rainfall events, with the highest recorded amount being 47.67 mm. Significantly, the majority of these exceptional occurrences took place in December and April, highlighting distinct seasonal trends.
By contrast, the top 10 days of extreme rainfall in Mpwapwa District, documented from 1981 to 2022, exhibited greater intensity than those in Bahi. The most intense rainfall event reached 68.2mm on 06th Apr 2016. The precipitation extremes in this location are greater than the levels observed in Bahi. These events primarily took place in April and December, indicating comparable seasonal trends.
The National Environment Strategy (URT, 2021) reports flooding in several Tanzanian districts, including Mpwapwa and Bahi districts. The flooding in 2009 and 2010 displaced many people. Twenty-three thousand nine hundred eighty people were displaced in Kilosa, 19,000 in Mpwapwa, and 19,000 in Kongwa. Flood-damaged infrastructure and services cost Tshs 329 billion in Kilosa and Mpwapwa.
The districts of Bahi and Mpwapwa have witnessed notable instances of heavy rainfall, with the most severe incidents being documented in the year 2020. The intensity of extreme events in the Bahi district is typically milder in comparison to those in Mpwapwa, indicating regional disparities in rainfall patterns. The clustering of extreme events during particular months indicates clear seasonal patterns. The inclusion of recent years, particularly 2020, in the historical data of the highest rainfall extremes for both districts may suggest a rising pattern of increasingly intense rainfall occurrences, potentially influenced by broader climatic shifts.

Temperature Trend in Bahi and Mpwapwa

Average Annual Maximum and Minimum Temperature

Both Mpwapwa and Bahi Districts exhibit elevated mean annual minimum and maximum temperatures, as depicted in Figure 10. The linear trends of the minimum and maximum temperatures are statistically significant, suggesting a consistent and gradual rise over time. The regression lines for Bahi and Mpwapwa districts have slopes of 0.0244 and 0.0221, respectively. This indicates a gradual increase in the average annual maximum temperatures for both districts.
The recorded mean annual maximum temperature in Bahi in 1981 was 28.619˚C. The linear regression model explains 34.37% of the variation in temperature data, as indicated by an R^2 value of 0.3437. This suggests a moderate level of correlation between the year and the average annual maximum temperature.

Table 2: Top 10 days of extreme rainfall for Bahi district 1981-2021

Date	09/12/ 1996	27/12/ 2009	20/12/ 1985	02/04/ 2012	09/12/ 2018	02/04/ 2014	11/12/ 2011	13/12/ 2011	14/04/ 1990	16/03/ 2020
Rain (mm)	47.7	44.3	43.6	42.4	39.0	38.7	37.9	37.9	37.2	36.3

Source: Computation based on TMA 2022

Table 3: Top 10 days of extreme rainfall for Mpwapwa District 1981-2021

Date	06/04/ 2016	01/04/ 2009	13/12/ 2012	08/04/ 2000	08/04/ 1986	01/01/ 1990	21/12/ 1997	12/04/ 1990	31/12/ 2004	14/01/ 2020
Rain (mm)	68.2	60.7	60.3	55.2	54.6	53.0	52.8	51.9	51.8	51.2

Source: Computation based on TMA 2022

In contrast, the equation for Mpwapwa can be represented as y = 0.0221x + 27.016, which signifies that the average highest temperature experienced annually rises by approximately 0.0221 degrees Celsius per year. The average highest temperature in 1981 was 27.016˚C. The regression equation accounts for 40.86% of the variability in the temperature data, as indicated by an R^2 value of 0.4086. This suggests a moderate to high level of linearity between the year and the mean annual maximum temperature. This indicates a significant rise in temperatures over the years for both districts.

The Bahi district exhibits a positive linear correlation between the year and minimum temperature, with an annual increase of 0.0162 ˚C, as depicted in Figure 11. Conversely, the Mpwapwa district demonstrates a more pronounced yearly rise in minimum temperature compared to Bahi. With an R^2 value of 0.5109, the model accounts for 51.09% of the variability in the Mpwapwa district's minimum temperature data, indicating a moderate relationship between the year and minimum temperature. Collectively, these findings highlight progressive temperature changes in both districts, revealing distinct patterns and potential impacts on the regional climate and ecosystems and the need for tailored adaptation measures.

Comparatively, the observed trend of rising temperatures aligns with the findings of other researchers. Scholars such as (Mayaya et al., 2015; Mkonda & He, 2017; Helena Elias Myeya, 2021) have similarly asserted that there is a general upward trajectory in overall temperatures in semi-arid areas where these studies were conducted.

Descriptive statistics were used to summarise the data. In the Bahi District (Table 3), the temperature data collected over a span of 41 years indicated that the lowest recorded temperature was 16.10°C, while the highest recorded temperature was 28.30°C. The mean temperature ranged from 16.68°C to 27.49°C, with a standard deviation of 0.316°C and 0.410°C for the minimum and maximum temperatures, respectively. This suggests that the temperature remained relatively stable during the given period.

On the other hand, the temperature data of the Mpwapwa District (Table 4), which spanned 41 years, revealed a minimum temperature range of 16°C to 17°C and a maximum range of 26°C to 28°C. The average values for the highest and lowest temperatures were comparable to those of Bahi, approximately 27.48°C and 16.68°C, respectively.

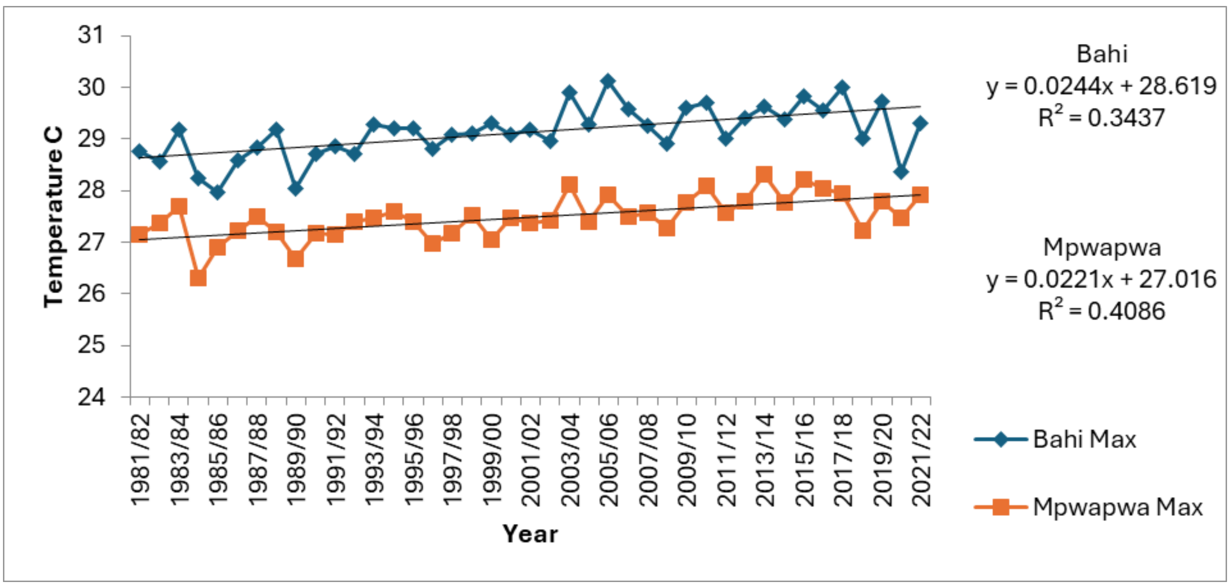

Figure: 8 Average annual maximum temperature for Bahi and Mpwapwa stations
Source: Computation based on TMA

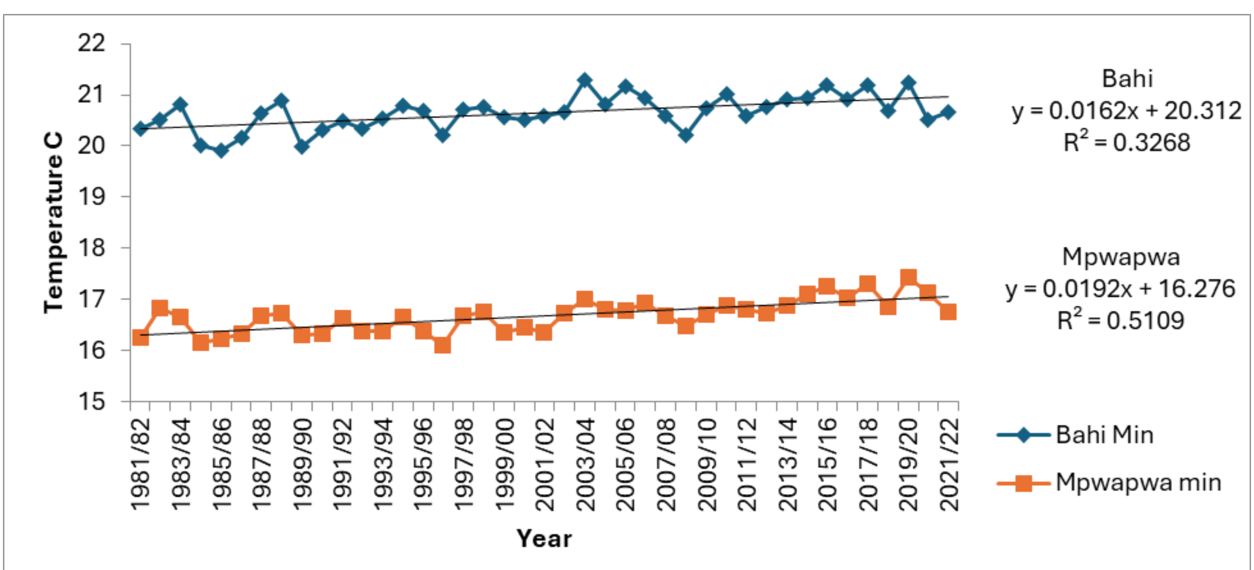

Figure 9: Bahi and Mpwapwa station's mean annual minimum temperature
Source: Computation based on TMA

The standard deviations for the maximum (0.415°C) and minimum (0.321°C) temperatures in Mpwapwa were slightly higher compared to Bahi District, indicating a slightly greater degree of temperature variability over the years. Both datasets offer vital perspectives on the climatic patterns and fluctuations in the regions, with implications for agricultural planning, environmental policy, and strategies to adapt to climate change.

Average monthly temperature

The average monthly temperature for both stations vary throughout the year, Mpwapwa (Figure 12) shows the highest maximum temperature in October at 28.7°C and the lowest in June at 25.7°C. The highest minimum temperature occurs in November at 16.5°C and the lowest in May at 16.6°C. On the other hand, the average monthly maximum temperature for Bahi (Figure 13) ranges from 28.8°C in March to 31.4°C in October, with the highest value occurring in October. The lowest maximum temperature occurs in July at 27.0°C. The average monthly minimum temperature ranges from 17.9°C in November to 20.6°C in May, with the lowest in November and the highest in May. Bahi generally has higher average temperatures than Mpwapwa, with higher maximum and minimum temperatures, too. However, both locations experience similar temperature trends throughout the year, with the highest in October/November and the lowest in May.

These findings corroborate the observations made by (Mkonda & He, 2017; Mtupile & Liwenga, 2017), indicating that although average temperatures have risen, seasonal extremes amplify significantly. More precisely, the colder months are characterized by lower temperatures, while higher temperatures mark the hotter months. Furthermore, semi-arid areas are experiencing substantial variations in temperature between November and March, consequently impacting agricultural output and the well-being of livestock (Mkonda & He, 2017).

Table 4: Descriptive Statistics of Bahi District Temperature 1981 - 2021

	N	Minimum	Maximum	Mean	Std. Deviation
Minimum	41	16.10	17.40	16.6756	0.31605
Maximum	41	26.30	28.30	27.4878	0.41000

Source: Computation based on TMA

Table 5: Descriptive Statistics of Mpwapwa Temperature 1981 -2021

	N	Minimum	Maximum	Mean	Std. Deviation
Max Temp	41	26	28	27.48	.415
Min Temp	41	16	17	16.68	.321
Valid N (listwise)	41				

Source: Computation based on TMA

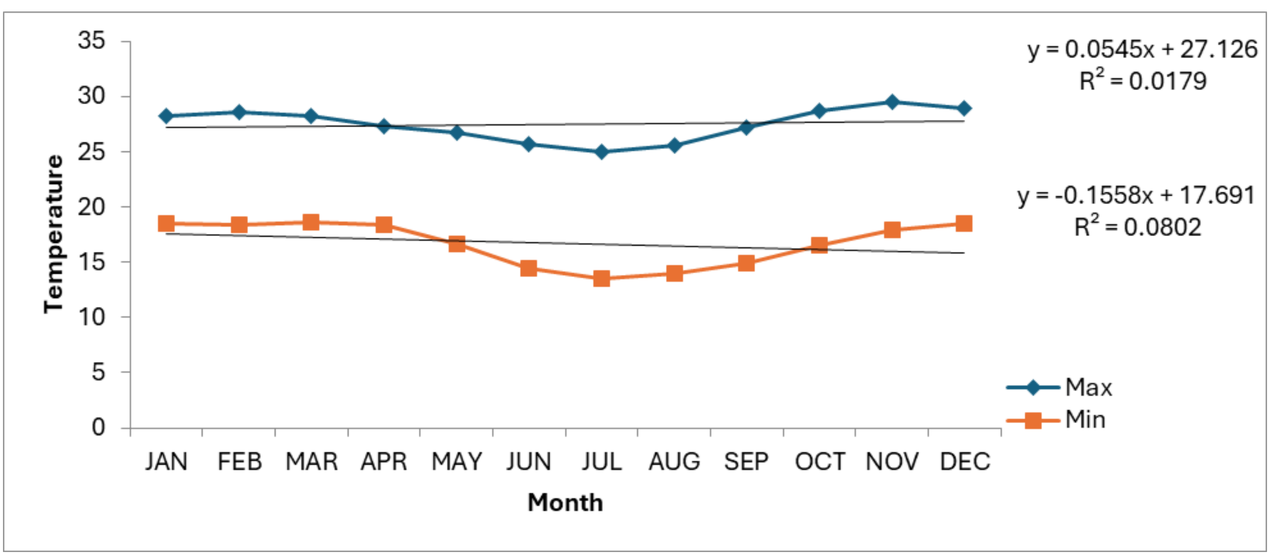

Figure 10: Monthly average temperature of Bahi District from 1981 to 2021
Computation based on TMA

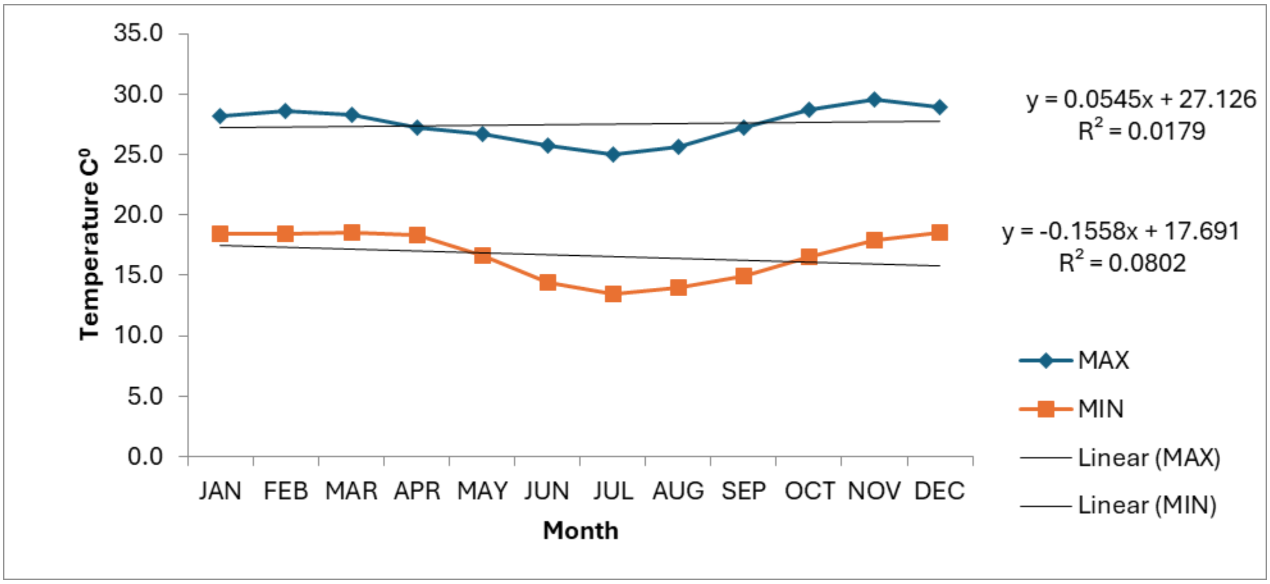

Figure 11: Mean monthly temperature for Mpwapwa District from 1981 to 2021
Computation based on TMA

Conclusions

The study's findings provide a detailed perspective on the trends of rainfall and temperature in the Mpwapwa and Bahi districts of Tanzania. These findings uncover both overall patterns and specific anomalies that have occurred over the past forty years. Rainfall analysis indicates a slight increase in annual precipitation in both districts, though the trends are neither linear nor consistent, featuring periods of both decline and significant increase. The rainfall variability is emphasised by the descriptive statistics, indicating a moderate level of variability around the mean for both districts. However, Mpwapwa shows a wider range and more significant fluctuations compared to Bahi. The decadal rainfall analysis demonstrates significant temporal variation, with Mpwapwa showing a notable decline in annual rainfall over the past three decades, except for the most recent one.

The study also highlights the variability and complexity of rainfall patterns, as evidenced by the average monthly and decadal rainfall analyses. Both districts experience a single period of intense rainfall, occurring primarily in December and January. However, the rainfall patterns exhibit considerable variability and can have a significant impact on agro-pastoral systems. The trend analysis indicates a steady rise in the number of rainy days in Mpwapwa and a small decline in Bahi. However, there are notable variations from year to year, which are influenced by broader climatic factors. The examination of precipitation extremes additionally demonstrates the magnitude and seasonal pattern of rainfall in these regions, with recent years, notably 2022, indicating a potential increase in occurrences of intense rainfall.

Temperature trends in both districts demonstrate a consistent and gradual increase over time, with both the average annual maximum and minimum temperatures displaying statistically significant upward trends. This increase in temperature corresponds with more extensive observations of the effects of climate change in semi-arid areas. The temperature variability is evident in the analysis of average monthly temperatures, revealing seasonal extremes and substantial variations between the warmer and colder months. The increasing temperature trend has consequences for the local climate, ecosystems, and agricultural practices, requiring customised adaptation strategies to reduce the possible negative impacts.

In general, the study highlights the complex and fluctuating characteristics of climate patterns in semi-arid areas such as Mpwapwa and Bahi. The results emphasise the necessity for reliable, region-specific climate data and analysis in order to comprehensively comprehend and adjust to these transformations with effectiveness. This knowledge is essential for providing information to guide agricultural planning, shape environmental policy, and develop strategies to strengthen resilience against climate variability and change. Continuous monitoring and analysis are crucial to anticipate and address the challenges and opportunities arising from the changing climate.

Credit authorship contribution statement

Samson Msilu: Initiated the work, collection and analysis of the research data. He was also responsible for securing funds for this research. **Amos E. Majule:** The main supervisor who reviewed the whole work. **Joseph Perfect:** Review, editing and supervision.

Declaration of Competing Interest

We, the authors, declare that this study has no competing interest and that this work is part of the PhD studies at the Institute of Resource Assessment of the University of Dar es Salaam (UDSM).

Data availability

Data regarding this study are available subject to the request.

Acknowledgement

The researchers acknowledge the Tanzania Metrological Agency for providing research data from 1981 to 2021, the community where the study took place, and all those who participated at various levels to complete this study.

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