ASSESSMENT OF TEMPORAL VARIABILITY OF TEMPERATURE AND PRECIPITATION TRENDS IN KARGI, MAIKONA, DAKABARICHA AND SOLOLO WARDS OF MARSABIT COUNTY, KENYA †

[ANÁLISIS DE LA VARIABILIDAD TEMPORAL DE LAS TENDENCIAS DE TEMPERATURA Y PRECIPITACIÓN EN EL CONDADO DE MARSABIT, KENIA]

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SUMMARY

Background. Climate change is a global phenomenon, with varying indicators and impacts from one region to another. The impacts of the changing climate are high in developing countries that are mainly dependent on climate-driven economic sectors such as pastoral and agro-pastoral livelihoods. **Objective.** Analyze the temporal trend, the variability in temperature and precipitation, and the relationship between both parameters to determine the influence of the El Niño phenomenon in Marsabit County, Kenya, from 1981 to 2021. **Methodology.** Daily rainfall and temperature data for the four study locations (Maikona, Kargi, Dakabaricha, and Sololo) were obtained. The analysis of extremes was the main method used in the analysis of the temporal and spatial variability of rainfall and temperature to establish the frequency and magnitude of climate variability in the study area. The seasonal mean plus or minus 1 Standard deviation for the entire period of study was used in the analysis of extremes. **Results.** Findings from trend analysis showed that rainfall trends have significantly increased in Marsabit County. Further, results on seasonal trends and variability of rainfall showed that March-April-May rainfall has been decreasing over the years. Below average rainfall has been experienced in Maikona in 2000 and 2011 with a magnitude of -42.9 mm, and -39.3 mm, respectively, while below average rainfall has been experienced in Kargi in 2000, 2009, 2011, and 2012 with a magnitude of -41.7 mm, -24.2 mm, -35.3 mm, and -34.3 mm, respectively. Analysis of the temperature trends and variability showed that both night and day temperatures have significantly increased over the years in Marsabit County. The magnitude of warming was found to be double that of cooling. The regression analysis further showed that there exists a negative correlation between temperatures and rainfall, implying that generally, rainfall decreases with increasing temperatures. **Implications.** This finding is important because it could help policymakers and people working on development in Marsabit County see what temperature and precipitation changes are happening locally. This could help them plan for climate change better. Both pastoral and agro-pastoral areas have been affected by both El Niño and La Niña activities, with the El Niño years recording the highest amounts of rainfall while the La Niña years recording the lowest amounts. **Conclusions.** This study recommends the use of rainwater harvesting during the October to December Season to take advantage of the increasing Trends and flood episodes associated with high magnitudes and frequencies of above average rainfall and use the same to cope with reduced rainfall in the March to May season.
Keywords: climate variability; temporal variability; precipitation trends; temperature trends; Marsabit County-Kenya.

RESUMEN

Antecedentes. El cambio climático es un fenómeno global, con indicadores e impactos variables de una región a otra. Los impactos del cambio climático son altos en los países en desarrollo que dependen principalmente de sectores económicos impulsados por el clima, como los medios de vida pastoriles y agropastorales. **Objetivo**. Analizar la tendencia temporal, la variabilidad de la temperatura y la precipitación, y la relación entre ambos parámetros para determinar la influencia del fenómeno de El Niño en el condado de Marsabit, Kenia. **Metodología**. Se obtuvo

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información de precipitación y temperatura diaria de 4 localidades (Maikona, Kargi, Dakabaricha y Sololo). El análisis de extremos fue el principal método utilizado en el análisis de la variabilidad temporal y espacial de la precipitación y la temperatura para establecer la frecuencia y magnitud de la variabilidad climática en el área de estudio. En el análisis de los extremos se utilizó la media estacional más o menos 1 desviación estándar para todo el período de estudio. **Resultados**. Los resultados del análisis de tendencias mostraron que las tendencias de lluvia han aumentado significativamente en el condado de Marsabit. Los resultados sobre las tendencias estacionales y la variabilidad de las precipitaciones mostraron que las precipitaciones de marzo, abril y mayo han ido disminuyendo a lo largo de los años. Se han experimentado precipitaciones por debajo del promedio en Maikona en 2000 y 2011 con una magnitud de -42,9 mm y -39,3 mm respectivamente, mientras que en Kargi se han experimentado precipitaciones por debajo del promedio en 2000, 2009, 2011 y 2012 con una magnitud de -41,7 mm, -24,2 mm, -35,3 mm y -34,3 mm respectivamente. El análisis de las tendencias y la variabilidad de la temperatura mostró que las temperaturas nocturnas y diurnas han aumentado significativamente a lo largo de los años en el condado de Marsabit. Se descubrió que la magnitud del calentamiento era el doble que la del enfriamiento. El análisis de regresión mostró que existe una correlación negativa entre las temperaturas y las precipitaciones, lo que implica que, en general, las precipitaciones disminuyen con el aumento de las temperaturas. **Implicaciones.** Este hallazgo es importante porque podría ayudar a los formuladores de políticas y a las personas que trabajan en el desarrollo en el condado de Marsabit a ver qué cambios de temperatura y precipitación están ocurriendo localmente. Esto podría ayudarlos a planificar mejor para el cambio climático. Tanto las áreas de pastoreo como las agro-pastorales se han visto afectadas por las actividades de El niño y La Niña con los años El Niño ha registrado las cantidades más altas de lluvia mientras que los años La Niña se ha registrado las cantidades más bajas. **Conclusiones.** Este estudio recomienda el uso de la recolección de agua de lluvia durante la temporada de octubre a diciembre para aprovechar las tendencias crecientes y los episodios de inundación asociados con las altas magnitudes y frecuencias de lluvia por encima del promedio y usar lo mismo para hacer frente a la reducción de lluvia en la temporada de marzo a mayo.
Palabras clave: variabilidad climática; Variabilidad temporal; Tendencias de precipitación; Tendencias de temperatura; Condado de Marsabit-Kenia.

INTRODUCTION

Climate variability has significantly impacted pastoral and agro-pastoral livelihoods, especially in agricultural sectors worldwide, in the twenty-first century (Muoki, 2020; FAO, 2018). The climate variability is necessitated by weather events like seasonality in temperature, precipitation pattern, and reliability, which influence livestock development, crop growth, and subsequent yields. Research by Yamba *et al.* (2019), Pereira (2017), Serdeczny *et al.* (2016), and Somboonsuke *et al.* (2018) found that seasonal changes in temperature and rainfall impact crop yield, quantity, quality, and livestock production. According to Intergovernmental Panel on Climate Change (IPCC) reports, changes and fluctuations in the climate have put global food security at risk. This is primarily due to the variability in rainfall and temperature changes, the fact that rain cannot be predicted anymore, and the increased frequency of extreme weather events. As a result, crop yields, such as cereals, have declined in low-latitude areas while increasing in many high-latitude areas over the last few decades (IPCC, 2019). Furthermore, Hansen *et al.* (2006) discovered that over the last three decades, global temperatures have risen by 0.6 °C to 0.8 °C. In addition, Funk *et al.* (2012), Sarr (2012), and Collins (2011) investigated a higher temperature rise rate of about 0.023 °C yr^{-1} than global warming in West Africa and Chad over Africa, with an increasing rate of 0.016 °C yr^{-1}.

Climate variability has consistently threatened Kenya's livelihood options due to irregular rainfall, rising temperatures, and insufficient soil moisture. Temperatures have risen in western and central Kenya, especially during the long rainy season. As a result, the March-May season has shortened and become drier, while the October November December (OND) season has lengthened and become wetter, and annual rainfall has remained low (Sagero *et al.*, 2018; Ayugi and Tan, 2018; GOK, 2018). A study conducted in Kenya by Ochieng and Mathenge (2016) discovered that climate change has harmed the agricultural sector and will worsen due to these changes. For example, droughts struck Kenya in 1983-4, 1991-3, 1995-6, 1998-2000, 2004, 2008-9, 2014, and 2017, and El Niño rains caused floods in 1985, 1997-1998, 2000, 2007, 2015, and 2018 (GoK, 2018; Orindi and Ochieng, 2005). According to the 2018 National Climate Change Action Plan (NCCAP), extreme weather events can be monitored by measuring climatic parameters such as wind, pressure, temperature, and rainfall (GoK, 2018).

Africa warmed by about 0.05°C per decade during the twentieth century. According to model projections of potential greenhouse gas-induced climate variability, temperatures will continue to rise. As a result, the situation will deteriorate, resulting in a slightly higher sea-level rise (IPCC AR6, 2021). Kenya has seen rising temperatures and decreasing annual rainfall trends, with high seasonal variability in many parts of the country (Government of the Netherlands, 2019; USAID, 2018). Kenyan temperatures have risen by one degree Celsius over the last 50 years, and this trend is expected to continue, with temperatures rising by nearly three degrees by 2050. As seasonal rainfall has failed, droughts have become more common in many parts of the world, including Kenya. Droughts used to happen every nine to ten years, but the gap appears to be shrinking every two to three years. The climate of East Africa, particularly its rainfall, is notorious for its inter-annual variability, which has frequently resulted in severe and recurring droughts and floods (Tierney *et al.*, 2015). The El-Nino Southern Oscillation (ENSO), the Indian Ocean Dipole (IOD), and the movement of the inter-tropical convergence zone (ITCZ) all contribute to this (Endris *et al.*, 2018).

According to the 2010 National Climate Change Response Strategy paper, the country's daytime and night-time temperatures in the western part of Kenya have risen by up to 2.1 °C and 2.9 °C, respectively, over the previous twenty years. Meanwhile, temperatures in critical parts of Kenya, including Nairobi, have increased by 2.0 °C and 0.7 °C, respectively. Furthermore, temperatures in the rift valley's southern-jap region, which includes Kenya's food basket, have risen by 1 °C. From 1966 to 1999, the maximum and minimum temperatures in Nairobi increased. Due to climate variability, Kenyan authorities have spent approximately Kenya Shillings (KES) 37 billion. According to the Kenyan government (2018), development agencies spent KES 194 billion on programs deemed to impact global warming components between 2005 and 2015. Residents in Marsabit County are experiencing rising temperatures and varying rainfall amounts. Many studies have revealed that the relationship between temperature and precipitation varies spatially and seasonally. Caesar and Lowe (2012) investigated the relationship between average annual temperature and extreme precipitation using the HadGEM2 model. They discovered a significant correlation between the two. Dai et al. (1999) discovered a robust negative correlation between precipitation, maximum temperature (Tmax), and diurnal temperature range at short timescales globally during the warm season. A negative correlation between summer precipitation and temperature was discovered for most of the continental United States, indicating that warm summers are dryer and colder summers are wetter (W. Zhao and M. A. K. Khalil 1993). Analyze the temporal trend, the variability in temperature and precipitation, and the relationship between both parameters to determine the influence of the El Niño phenomenon in Marsabit County, Kenya, from 1981 to 2021. In order to actively engage in different phases of planning with sound choices, it is necessary to comprehend both historical and present trends in rainfall and temperature patterns. There isn't much information in the books about Marsabit precipitation variations, trends, and periodicities. Therefore, the purpose of this research was to tackle the issue of whether there were rainfall and temperature patterns over Marsabit County from 1981 to 2021 and the processes that caused them. The evaluation of long-term rainfall patterns at seasonal and annual time scales advances our knowledge of how precipitation and temperature have changed historically. Thus, this research will increase our understanding of climate change over the study location and serve as a resource for assessing the vulnerability of water resources and agro-pastoral sectors to climate change. The results of this study can assist policymakers at the county level and local communities in developing sustainable water resources, agro-pastoral plans, and adaptation strategies in the wake of a changing and variable climate.

MATERIALS AND METHODS

Study Area

This research was conducted in Marsabit County, located in upper eastern Kenya, between latitudes 02º 45'N and 04º 27'N and longitudes 37º 57'E and 39º 21'E. Marsabit County has an area of approximately 70,961 km^2 and is made up of a flat plain with elevations between 300 m and 900 m (Fig. 1). The County has a population of 459,785 people (243,548 males and 216,219 females) living in 77,495 households (KNPS, 2019). The county has a population density of four people per square kilometre. Marsabit's poverty index is very high (83.2%), ranking 44th out of 47 counties in Kenya (KNBS, 2019). Livestock keeping is the main economic activity in Marsabit County. The main livestock products are milk, beef, mutton, and camel meat. Crop production in Marsabit County does not thrive well because of erratic rainfall and an increasing incidence of recurrent droughts. There are, however, some areas around Mt. Marsabit and in Moyale sub-county where crop farming is practiced during the rainy seasons. Land is a primary factor of production in the economy and has aesthetic, cultural, and traditional values. Land types in the County are broadly classified as game reserves, townships, agriculture, and grazing lands, with the largest proportion under communal grazing areas. The absence of a national land use policy and spatial plan has encouraged the proliferation of informal settlement, inadequate infrastructure services, congestion, environmental degradation, unplanned urban centres, pressure on agriculture and grazing land, and inter-tribal conflicts, among others.

Marsabit County has a cool and dry climate with two rainy seasons (bimodal) ranging from 600 to 1000 $mmyr^{-1}$ (Bake, 1983). The March to May season is termed as Long rains fall, while the October to December season is termed as short rains fall. The average temperature during the hot season is 30–35 ºC across the county, with February being the Month with the hottest (high) temperatures. In contrast, March and July have the lowest temperatures, ranging from 22 to 25 degrees Celsius (Cuni-Sanchez et al., 2018). Evaporation rates are pretty high, with total annual potential evaporation in the 1800–2200 mm range. For easy interpretation, we classify the four study sites into two (2); Drier (Kargi and Maikona) and Wetter (Sololo and Dakabaricha) regions.

Data collection

Meteorological data records from 1981 to 2021 were collected from the four study stations in Marsabit County. Daily rainfall data for the four locations (Maikona, Kargi, Dakabaricha, and Sololo) for the period 1981-2021 were obtained from CHIRPS, gridded at a resolution of 0.05^0x 0.05^0 (approximately 5km x 5km over land), and daily maximum and minimum temperature data were obtained from the ECMWF Re-Analysis, ERA5. The climate information represented the most current mean climate in the study areas. The 40-year period was long enough to show several unusual weather patterns in Marsabit County, such as monthly changes in rainfall and temperature. A summary check sheet was used to record the precipitation and temperature variations for Marsabit County, which included seasonal rainfall, yearly rainfall, and maximum and minimum temperatures.

Data Analysis

The observed climate data was analyzed at 95% confidence intervals using the Statistics Kit for Social Sciences (SPSS) spreadsheet version 24 and MS Excel software. The study's average rainfall and temperature data regions were provided by CHIRPS and ECMWF. After that, the inter-annual standard deviation and variance of precipitation and temperature were computed simultaneously. Pearson moment correlation analysis was used to discover the basic relationship between a pair of variables (Ficklin *et al.*, 2015; Oguntunde *et al.*, 2017). Correlation analysis was employed to establish if there are some statistically significant relationships between their time series. ENSO (El Niño-Southern Oscillation) is a climate pattern that occurs across the Pacific Ocean, while the Palmer Drought Severity Index (PDSI) is an index that uses readily available temperature and precipitation data to estimate relative dryness. It is a standardized index that generally spans -10 (dry) to +10 (wet). The PDSI is one of the indices of the relative dryness or wetness affecting water-sensitive economies. The simple correlation (r_{xy}) between variables *X* El Niño-Southern Oscillation (ENSO-index) and *Y* Palmer Drought Severity Index (PDSI) is expressed as (Pearson moment correlation):

$$r_{xy} = \frac{\sum_{i=1}^{n} \left\{ (x_i - \bar{x})(y_i - \bar{y}) \right\}}{\sqrt{n \sum_{i=n}^{n} \left\{ (x_i - \bar{x})^2 (y_i - \bar{y})^2 \right\}}}$$

where $-1 \le r_{xy} \le 1$. If the value of r_{xy} is +1 or –1, it implies that there exist a perfect positive or negative correlation between variables x.

The statistical significance of r_{xy} was be tested using the student's t-statistics.

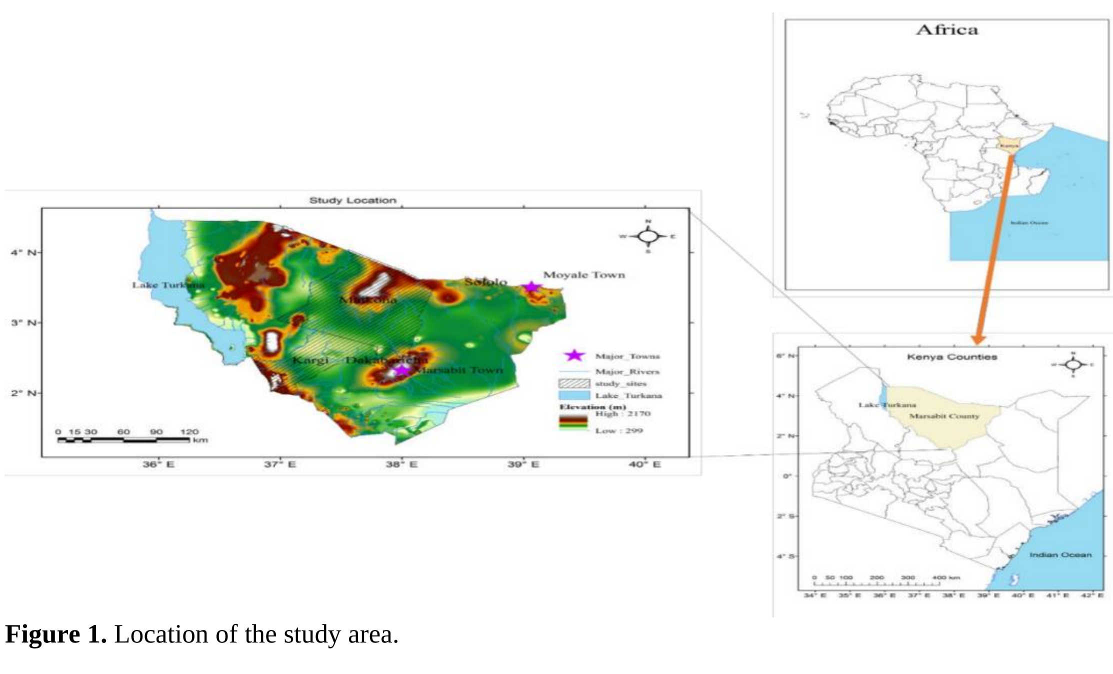

Figure 1. Location of the study area.

The methods used to analyse rainfall and temperature trends, variability, and the relationship between temperatures and rainfall were primarily statistical. Primary data was analysed using statistical software such as SPSS and Rstudio, as follows:

Analysis of extremes. The analysis of extremes was the main method used in the analysis of the temporal and spatial variability of rainfall and temperature to establish the frequency and magnitude of climate variability in the study area. Seasonal mean plus or minus 1 Standard deviation for the entire period of study was used in the analysis of extremes.

The equation for extremes is given by**: É=μ±σ**

Where:
É stands for extremes, which are departures from the Mean.
μ stands for the Population mean, which is the Mean of Means.
σ stands for one Standard deviation, which represents 67% of the data.

Trend analysis

Rainfall and temperature data were subjected to trend analysis, and the variation of rainfall and temperatures over years and seasons in the four stations in question was obtained. Both the temporal and spatial variations of temperatures and rainfall were established.

Significance test

Rainfall and temperature data were subjected to an analysis of significance to establish the magnitude of change in the slope of trends as interpreted from the P values for chi-square statistical analysis:

Regression analysis

Temperature and Rainfall data were subjected to Simple linear regression analysis, whereby temperature data was used as the independent variable **(X)** while rainfall data was used as the dependent variable (Y). The type of relationship between temperatures and rainfall and the magnitude of the effect of temperatures on rainfall were established from the sign and magnitude of the coefficients (b).

Equation for regression analysis

A simple linear regression equation was used where there is a linear relationship between the independent and dependent variables.

RESULTS AND DISCUSSION

Rainfall trends

Annual Rainfall Trend for Drier areas

Figure 2 indicates an analysis of variation between rainfall years, which shows that the rainfall trend in Marsabit County changed from 1981 to 2021. According to the study, the highest average annual rainfall in 1997 ranged from 427.4mm to 416.5mm in the pastoral areas of Kargi and Maikona. In 2000, the pastoral areas of Maikona and Kargi received the lowest annual rainfall of 59mm and 64mm, respectively. Analysis of the annual trends showed that Rainfall has slightly increased over the years in the Kargi and Maikona regions. The analysis of the annual variability of rainfall showed that both above average and below average rainfall have been experienced, which implies that both flood and drought episodes have been experienced. The years 1997, 2020, and 2000 in Kargi and Maikona experienced the highest deviation from the mean of 118.8 mm, 136.4 mm, and -66.2 mm in Maikona and the mean of 117.2 mm, 124.2 mm, and -78.3 mm in Kargi, respectively (Tab. 1). This implies that the region experienced the worst floods and droughts in 1997, 2020, and 2000, respectively. This could be related to EL-NIÑO, LA NIÑA and Tropical cyclone effects experienced over the years. This can be linked to the 1997 El Niño when the entire country received above-average rainfall (Ochieng *et al.,* 2022). El Niño events occurred in the country in 1985, 1997, and 2015, with the 1997 event recording the highest rainfall. The El-Niño weather phenomenon caused heavy rains in Kenya between May 1997 and February 1998. This ten-month heavy rainfall has resulted in widespread landslides and floods in various parts of the country.

Table 1 is a summary of annual rainfall trends in the pastoral (drier) regions of the study, rainfall amounts, and deviation from the mean.

Annual Rainfall Trend for Wetter areas

Figure 3 shows that the agro-pastoral zones of Dakabaricha and Sololo had a maximum annual rainfall of 1197.2 mm and 1170.3 mm, respectively. Similarly, results show that the agro-pastoral zones of Dakabaricha and Sololo have been experiencing increasing trends in rainfall from 1981 to 2021, and the change has been significant. The highest average annual rainfall in 1997 ranged from 768.6mm to 720.7mm in the Agro-pastoral areas of Dakabaricha and Sololo, respectively. This can be linked to the 1997 El Nino phenomenon (Ochieng *et al.*, 2022). In 2000, the agro-pastoral areas of Dakabaricha and Sololo received the lowest annual rainfall of 177mm and 301.1 mm, respectively. This could be associated with

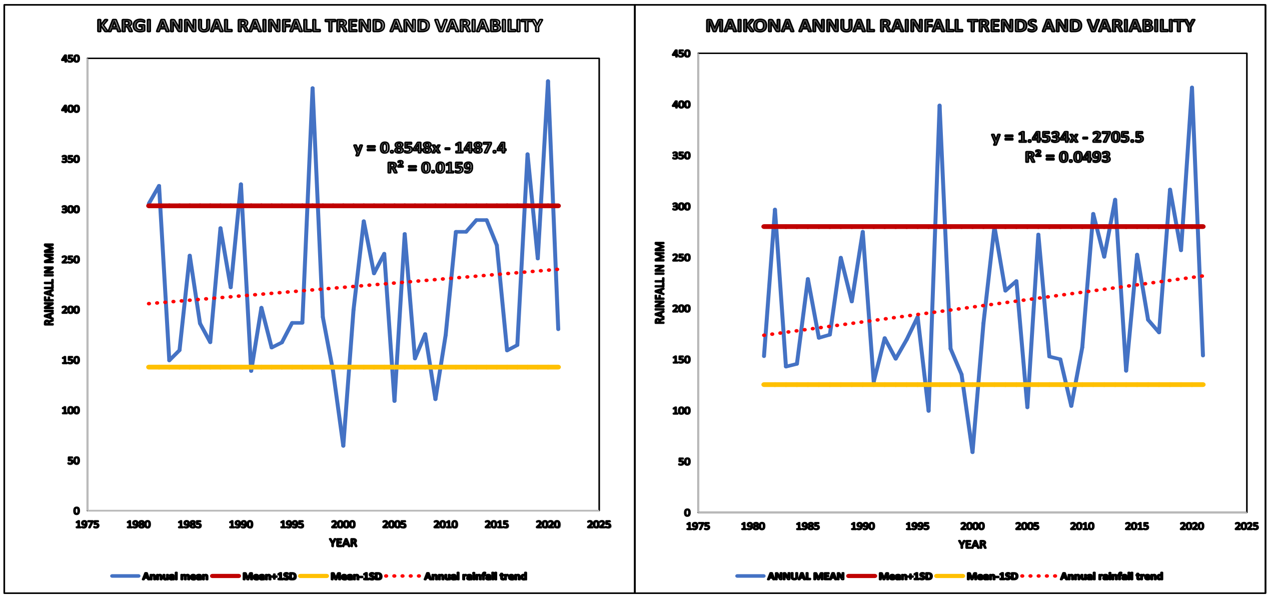

Figure 2. Annual Rainfall (mm) Trend for Kargi and Maikona Wards of Marsabit County (1981 - 2021).

Table 1. Annual Trends and variability of Rainfall in drier (Pastoral) regions of the study.

Study region	Year	Rainfall (mm)	Deviation
Kargi	1997	420.4	117.2
	2020	427.4	124.2
	2000	64.4	-78.3
Maikona	2020	416.5	136.4
	1997	398.9	118.8
	2000	59	-66.2

the LA NINA phenomenon. The study findings show a remarkable rise in rainfall (yearly) in the region from 1981 to 2021, as shown by the trend line (Fig. 3). The result of the study depicts that annual rainfall trends for March to May rainfall have been decreasing over the years in Sololo and Dakabaricha. Some years have been experiencing above average rainfall while others below average. Above average rainfall has been experienced in Sololo during March April May (MAM) in 2003, 2013, 2018, with a magnitude of 59.11, 59.71, and 114.81 mm, respectively, while in Dakabaricha, above average rainfall has been experienced in 1988, 2013, 2018, 2020, with a magnitude of 99.71mm, 57.81mm, 119.91 mm, and 97.91 mm, respectively. Below average rainfall has been experienced in Sololo during MAM in 2000 and 2011 with a magnitude of -107, -111.1 mm respectively while below average rainfall was experienced in Dakabaricha during MAM in 1984, 2000, 2009, and 2011 with a magnitude of -30.78, -110.88, -63.38, -88.18 respectively (Table 2).

The analysis further indicates that OND rainfall has been increasing over the years in Sololo and Dakabaricha. Some years have experienced above average rainfall while others have been within average. Above average rainfall has been experienced in Sololo during OND in 1997, 2006, and 2019 with a magnitude of 360.6mm, 121.9mm, 271.4 mm, and 140.3 mm, respectively, while above average rainfall has been experienced in Dakabaricha during OND in 1997, 2006, and 2019 with a magnitude of 388.6mm, 101.3 mm, 236.7 mm, and 146.1 mm, respectively. These being EL-NINO years, it verifies that indeed OND rainfall is greatly enhanced by ENSO activities, particularly EL-NINO in the area of study. In conclusion, rainfall trends have significantly increased in Marsabit County. Both pastoral and agro-pastoral areas have been affected by both EL NINO and LA NINA ENSO activities, with the EL NINO years recording the highest amounts of rainfall and the LA NINA years recording the lowest amounts.

These variabilities in rainfall shown in the research above back up the argument that high rainfall variability has harmed the Arid and semi-arid lands (ASALs) in Kenya (Omoyo et al., 2015). The findings are in line with those of Gichangi et al. (2015), discovered irregular (negative) anomalies and high seasonal variation in precipitation in semi-arid areas of Eastern Kenya, with 49 percent for MAM rains and 58 percent for OND rains. The study is also consistent with Muhati et al. (2018a) research, which found that average precipitation decreased by 6 millimetres for 53 yr-1 (1961 - 2014). Further, they discovered that MAM and OND rains decreased by 10 and 2 millimetres each year, respectively. The findings of this study contradict the rainfall recovery narrative and provide a scenario that contradicts the IPCC's projections for the overall rainfall distribution in eastern Africa. According to Koech (2015), this could be caused by anthropogenic activities that harm vegetation cover, resulting in a human-caused change in climate. Rainfall variability and distribution are critical climatological parameters when determining an area's temperature and precipitation trends. The study concludes that there have been no significant changes in annual rainfall amounts in the study region, except for a slight increase in some areas due to a rise in short rains. This is a vital record because it reveals localized, long-term rainfall trends that can be used to predict future rainfall events in these areas.

Table 2 gives a summary of the rainfall deviation and the amounts from the mean for the agro-pastoral (Wetter) region of the study during the study period.

Seasonal Rainfall Trends in Marsabit County for Drier areas

The study's results show that extreme rainfall trends were seen in Marsabit County during both the long (MAM) and short (OND) rainy seasons (Fig. 4). The findings of the study show that MAM seasonal rainfall has been decreasing over the years in the drier regions of Kargi and Maikona. There has been variability in terms of rainfall amounts over the years in most of the study locations. Above average rainfall has been experienced in Maikona in 1988, 2013, 2018, and 2020 with a magnitude of 22.4 mm, 55.2 mm, 88.7 mm, and 23.1 mm, respectively, while below average rainfall has been experienced in Maikona in 2000 and 2011 with a magnitude of -42.9 mm and -39.3 mm, respectively. Above average rainfall has been experienced in Kargi in 1988, 1997, 2013, 2014, 2018, and 2020 with magnitudes of 19.11 mm, 18.5 mm, 27.3 mm, 27.3mm, 86.2 mm, and 36.2 mm, respectively. Below average rainfall has been experienced in Kargi during MAM in 2000, 2009, 2011, and 2012 with a magnitude of -41.7 mm, -24.2 mm, -35.3 mm, and -34.3 mm, respectively (Tab. 3). This could be attributed to the presence of tropical cyclones in Mozambique during the season, which hampered the ITCZ.

Table 2. Annual Trends and variability of Rainfall in the Wetter (Agro-pastoral) Regions of the study.

Study region	Year	Rainfall (mm)	Deviation
Sololo	1997	1197.2	340
	2000	301.1	-173.3
Dakabaricha	1997	1170.3	399.5
	2000	177	-277.3

The findings of seasonal rainfall trends for the MAM and OND seasons for the pastoral (drier) regions of the study are summarized in Table 3. The analysis indicates that MAM seasons have been slightly decreasing over the years while OND seasons have been increasing. This variation is likely to be brought about by local physical features such as the elevation and the presence of Lake Turkana and the adjacent Ethiopian highlands.

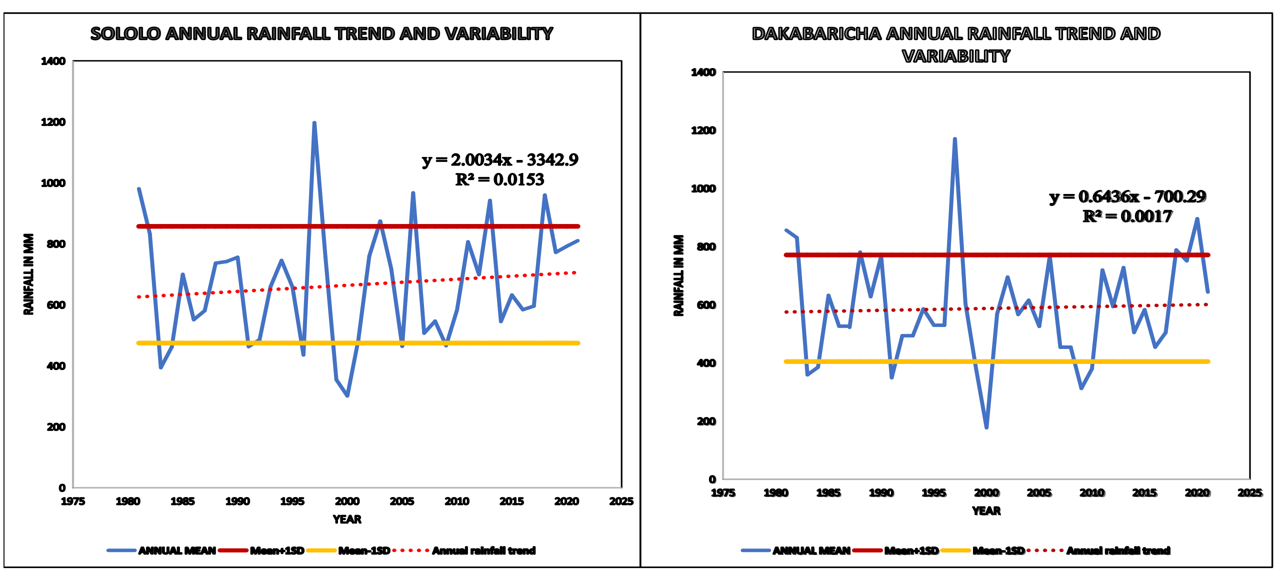

Figure 3. Annual Rainfall (mm) Trend for Dakabaricha, and Sololo wards of Marsabit County (1981 - 2021)

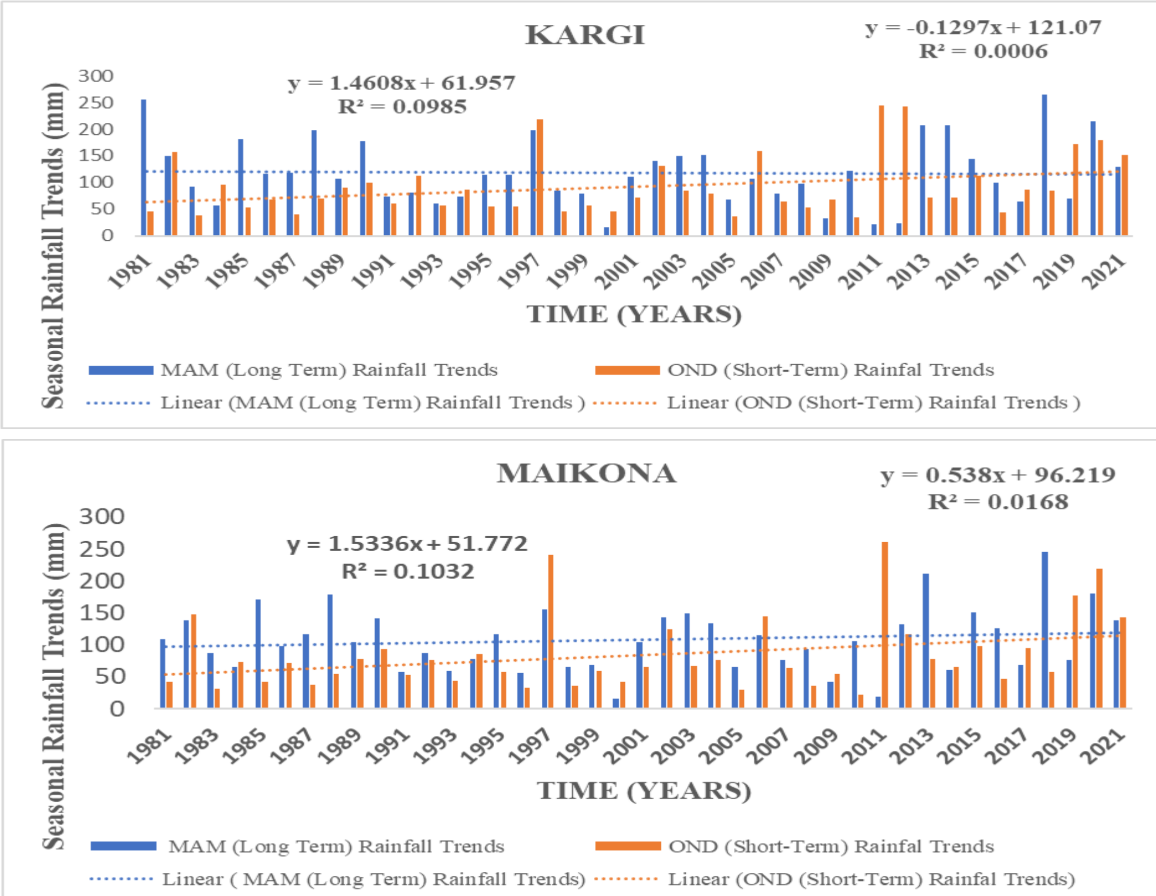

Figure 4. Seasonal Rainfall Trend for Kargi and Maikona wards of Marsabit County from 1981 to 2021.

Seasonal Rainfall Trends in Marsabit County for Wetter areas

The analysis of seasonal rainfall indicates that, contrary to the annual trends, MAM rainfall has been decreasing over the years in Sololo and Dakabaricha. Some years have seen above-average rainfall, while others have seen below-average rainfall. Above average rainfall has been experienced in Sololo during MAM in 2003, 2013, and 2018 with a magnitude of 59.11, 59.71, and 114.81 mm, respectively, while below average rainfall has been experienced in Sololo during MAM in 2000 and 2011 with a magnitude of -107 mm, and -111.1 mm, respectively. In addition, above average rainfall has been experienced in Dakabaricha during MAM in 1988, 2013, 2018, and 2020, with magnitudes of 99.71 mm, 57.81 mm, 119.91 mm, and 97.91 mm, respectively. Below average rainfall has been experienced in Dakabaricha during MAM in 1984, 2000, 2009, and 2011 with a magnitude of -30.78 mm, -110.88 mm, -63.38 mm, and -88.18 mm, respectively. This could be attributed to the presence of tropical cyclones in Mozambique during the season, which hampered the ITCZ.

Table 3. The frequency and magnitude of variability of pastoral rainfall in drier (Pastoral) region of the study.

	MAM Season				OND Season	
Study region	Year	Increase	Year	Decrease	Year	Increase
Kargi	1988	19.1	2000	-41.7	1997	71.1
	1997	18.5	2009	-24.2	2011	96.3
	2013	27.3	2012	-34.3	2012	94.3
	2014	27.3	2011	-35.3	2019	23.7
	2018	86.2			2020	32.5
	2020	36.2				
Maikona	1988	22.3	2000	-42.9	1997	100
	2013	55.2	2011	-39.3	2011	121.3
	2018	88.7			2020	78.5

Similarly, OND seasonal rainfall has been increasing over the years in Sololo and Dakabaricha. The analysis indicates that some years have experienced above average rainfall while others have been within average. Above average rainfall has been experienced in Dakabaricha in 1997, 2006, 2011, and 2019 with a magnitude of 388.6mm, 101.3 mm, 236.7 mm, and 146.1 mm, respectively. Further, below average rainfall has been experienced in Sololo in 1997, 2006, 2011, and 2019 with magnitudes of 360.6mm, 121.9mm, 271.4 mm, and 140.3 mm, respectively. These being EL-NIÑO years, it verifies that indeed OND rainfall is greatly enhanced by ENSO activities and particularly EL-NIÑO in the area of study (Fig. 5).

The findings of seasonal rainfall trends for the MAM and OND seasons for the agro-pastoral (wetter) regions of the study are summarized in Table 4. The analysis indicates that MAM seasons have been slightly decreasing over the years while OND seasons have been increasing.

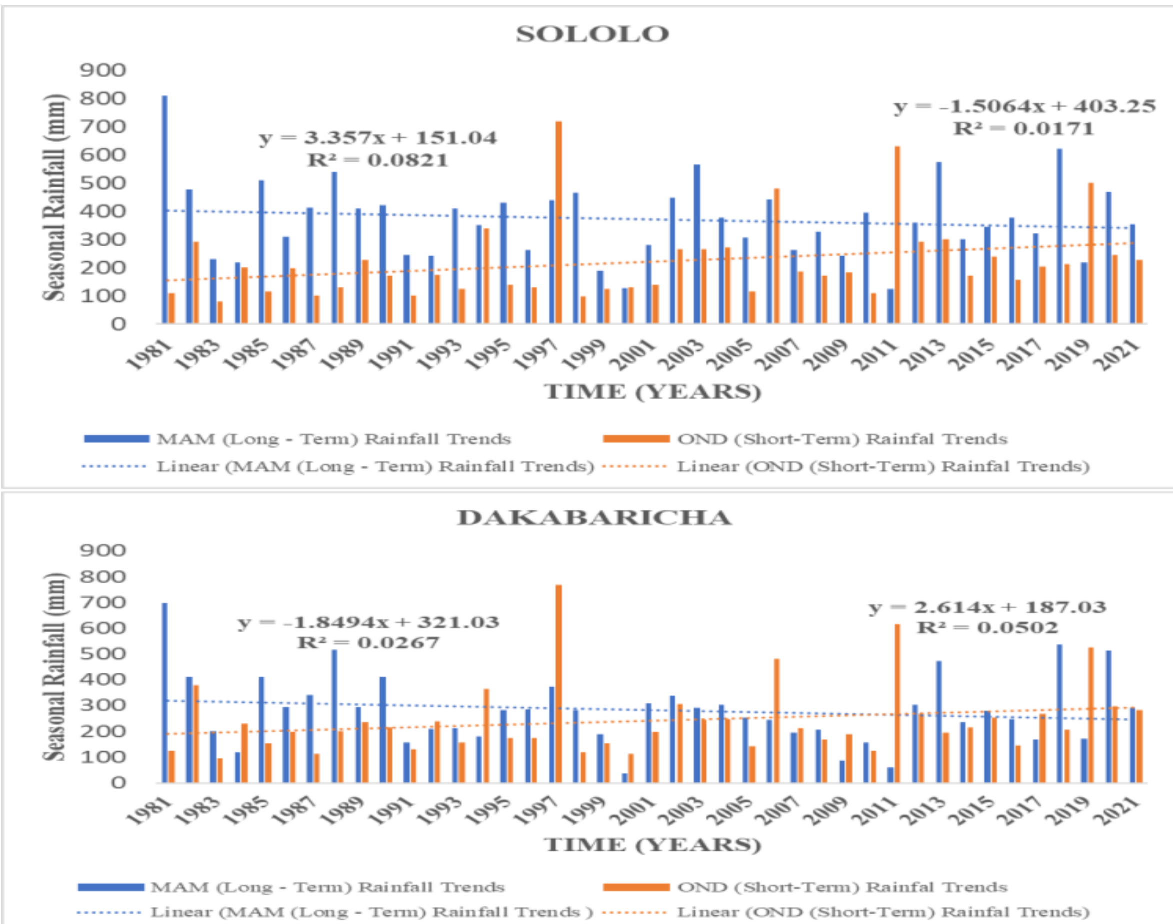

Figure 5. Seasonal Rainfall (mm) Trend for Dakabaricha and Sololo wards of Marsabit County from 1981 to 2021.

Table 4. The frequency and magnitude of variability of Seasonal rainfall in wetter (Agro-pastoral) region of the study.

	MAM Season				OND Season	
Study region	Year	Increase	Year	Decrease	Year	Increase
Sololo	2003	59.11	2000	-107	1997	360.6
	2013	59.71	2011	-111.1	2006	121.9
	2018	114.81			2011	271.4
					2019	140.3
Dakabaricha	1988	99.71	1984	-30.78	1997	388.6
	2013	57.81	2000	-110.88	2006	101.3
	2018	119.91	2009	-63.38	2011	236.7
	2020	97.91	2011	-88.18	2019	146.1

The IPCC 2021 report shows East Africa's rainfall patterns are because of the El Niño phenomenon, which concurs with the findings on the seasonal rainfall pattern fluctuations in Marsabit County. Similar research conducted in the ASALs of Kenya has shown irregular anomalies and high seasonal fluctuations in rainfall, with 49% for long rains and 58% for short rains (Gichangi et al., 2015). This is also consistent with research conducted in Kenya's Marsabit Forest Reserve by Muhati *et al.* (2018b) that showed that from 1961 to 2014, mean rainfall decreased by 6 mm per year. Research further indicates that MAM and OND rains decreased by 10 mm and 2 mm for the same period, respectively. Evidence shows that rainfall trends in Marsabit have declined for the last 53 years (1961 - 2014) with high variability (Muhati *et al.*, 2018a). The findings agree with those of Funk *et al.* (2010), who conducted a study on the trend of Kenya's spatial-temporal rainfall design and found similar results. It is important to note that the results of various studies conducted on temporal temperature and rainfall trends and variations at various sites over Marsabit County may vary owing to the elevation and other local and mesoscale features such as Lake Turkana, the Ethiopian highlands, and the Turkana jet stream, which tend to modulate the local weather patterns (Ochieng *et al.*, 2023). Other similar research that focuses on the study subject includes a survey conducted by Wakachala *et al.* (2015) in Kenya's Great Rift Valley, which revealed that rainfall had decreased annually, with significant seasonal variations, affecting production and decision-making. In addition, an analysis by Omondi *et al.* (2014) of rainfall at specific stations in the Horn of Africa revealed a decreasing trend in total rainfall in Southern Sudan, Western Ethiopia, and areas around Lake Victoria in Kenya. The findings of this study's long-term rainfall trend are useful information that indicates the magnitude of climate variability at the local level and can aid in formulating more informed mitigation and resilience-building policies for local communities in Marsabit County in the face of a globally changing climate.

Rainfall Variability in Marsabit County for Drier areas

The anomalies of annual rainfall variability characteristic of Kargi and Maikona, wards in Marsabit County, Kenya, were computed and plotted in Figure 6. The annual rainfall variation from year to year explicitly differs from the long-term mean in the past 40 years. The analysis clearly distinguishes between the driest and wettest years and shows significant variability in the mean precipitation amounts recorded during the study. Annual average rainfall variability from the long-term mean ranges from -158.60 mm (2000) to +214.40 mm (2000) in Kargi and -143.70 mm (2000) to +213.80 mm (2000) in Maikona. Higher amounts of rainfall anomalies were recorded during the research in the years 1982 (+100.2 mm), 1983 (-73.6 mm), 1990 (+101.8 mm), 1991 (-83.1 mm), 1997 (+197.4 mm), 2000 (-158.6 mm), 2009 (-112.2 mm), and 2020 (+204.4 mm) in Kargi, 1982 (+94.2 mm), 1997 (+196.2 mm), 2000 (-143.7 mm), and 2013 (+103.9 mm) in Kargi, 1982 (+94.2 mm), 1997 (+196.2 mm), and 2000 (-143.7 2014 (-63.9 mm), and 2020 (+213.8 mm) in Maikona.

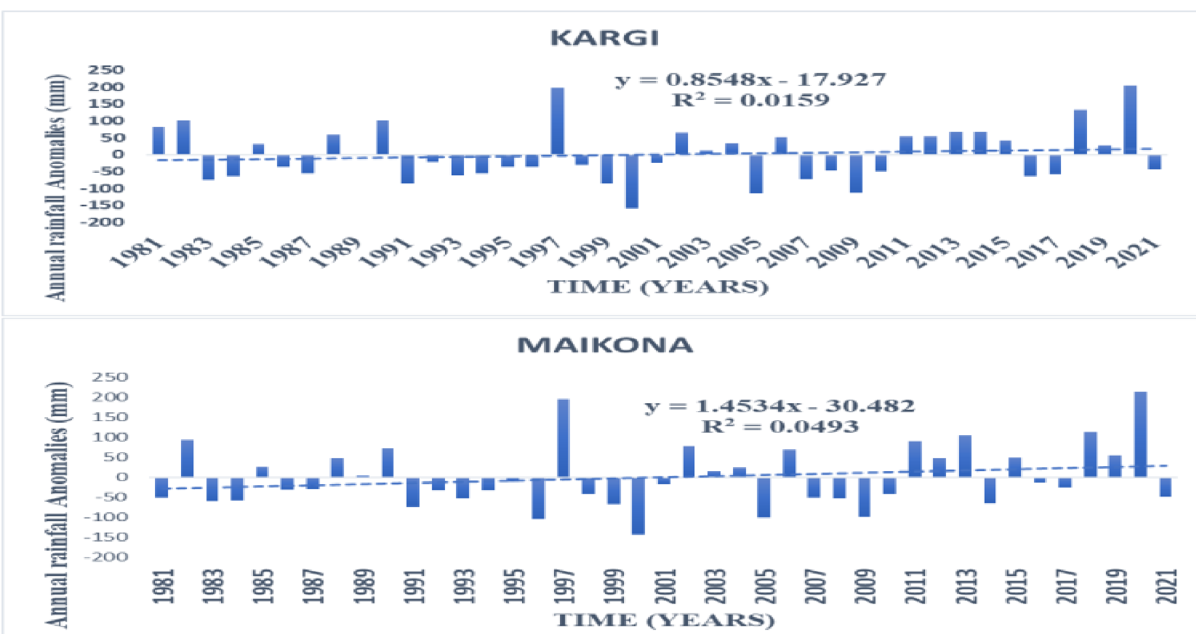

Figure 6. Annual Rainfall (mm) Variations for Kargi and Maikona wards of Marsabit County (1981–2021).

Rainfall Variability in Marsabit County for Wetter areas

Figure 7 depicts the inter-annual variability of rainfall over the wetter categories (Dakabaricha, and Sololo) of these elected study sites. Similar, variations were observed in the drier areas. These are -410.60 mm (2000) to +582.70 mm (2000) in Dakabaricha, and -364.70 mm (2000) to +531.40 mm (2000) in Sololo. The high amounts were observed in 1983 (-228.8 mm), 1997 (+582.7 mm), 2000 (-410.6 mm), 2006 (+180.1 mm), 2009 (-275.5 mm), and 2020 (+307.9 mm) in Dakabaricha, and 1981 (+134.6 mm), 1983 (-271.9 mm), 1997 (+531.4 mm), 2000 (-364.7 mm), 2006 (+301.1 mm), and 2009 (-199.9 mm). This study's findings align with those of Amwata et al. (2016), which confirm some of the driest (1984, 2000, 1996) and wettest (1998, 1980, and 2012) years in Kajiado County, a pastoralist county.

Flooding has historically occurred in Kenya during these wet years, and some of it has been linked to El Nino events, indicating that the function of ENSO cannot be disregarded as much as it has revealed climate variability. Furthermore, according to Mwaniki (2014), the El Nino years were 1982, 1986, 1987, 1991, 1997, and 2000. Some of these years are mentioned in the preceding discussion. Kisaka *et al.* (2015) reported that high rainfall variability is typically ascribed to La Niña and El Niño issues, despite the fact that they are not of equal measure and contribute substantially to unpredictable weather incidents. According to the findings, these events have become more severe and frequent in recent years. As a result, it is critical to develop mechanisms that will assist households in these areas in adapting to changing rainfall variability.Seasonal Rainfall Variations in Marsabit County for Drier areas.

Figure 8 depicts the seasonal rainfall variability analysis results for the long and short rainy seasons. Rainfall variability in the March-April-May season trend is significant, ranging from -102.9 mm in 2000 to +147.2 mm in 2018. Rainfall variability in the October to December season trend is also substantial, ranging from (-58.8 mm) in 2010 to (+151.3 mm) in 2011. During the MAM rainy season, the highest rainfall variations were recorded in 1981 (+136.6 mm), 1984 (-60.7 mm), 1985 (62.7 mm), 1988 (80.1 mm), 1990 (59.0 mm), 1993 (-58.6 mm), 1997 (79.5 mm), 2000 (102.9 mm), 2012 (96.3 mm), 2013 (88.3 mm), 2018 (+147.2 mm), and 2020 (97.2 mm) in Kargi, Maikona, Dakabaricha, and Sololo Respectively, for the OND rainy season, higher variations in rainfall were captured in 1981 (-47.2 mm) and 1982 (87.6 mm).

Seasonal Rainfall Variations in Marsabit County for Wetter areas

In the wetter areas (Fig. 9), there are higher changes in the observed seasonal rainfall variability, as noted by the higher gradient of the trend lines. The similarities can be seen in the 2000s, when larger variations were experienced in all the locations. Previous research (Bals et al., 2008; IITA, 2004) has exhibited that shifts in seasonal rainfall patterns are inadequate for rain-fed

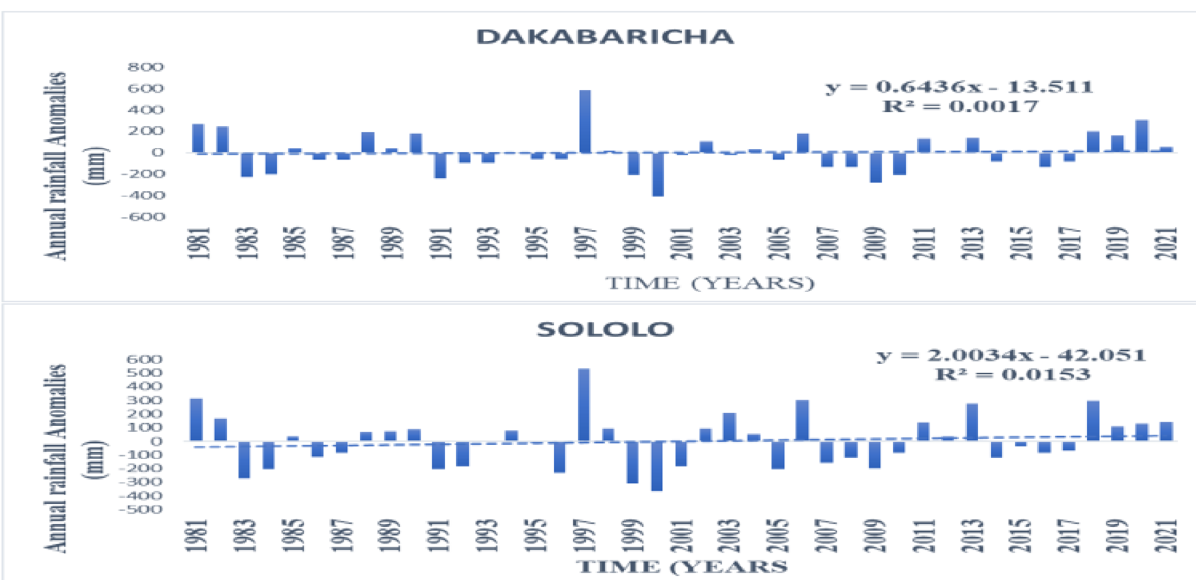

Figure 7. Annual Rainfall (mm) Variations for Dakabaricha, and Sololo wards of Marsabit County (1981–2021).

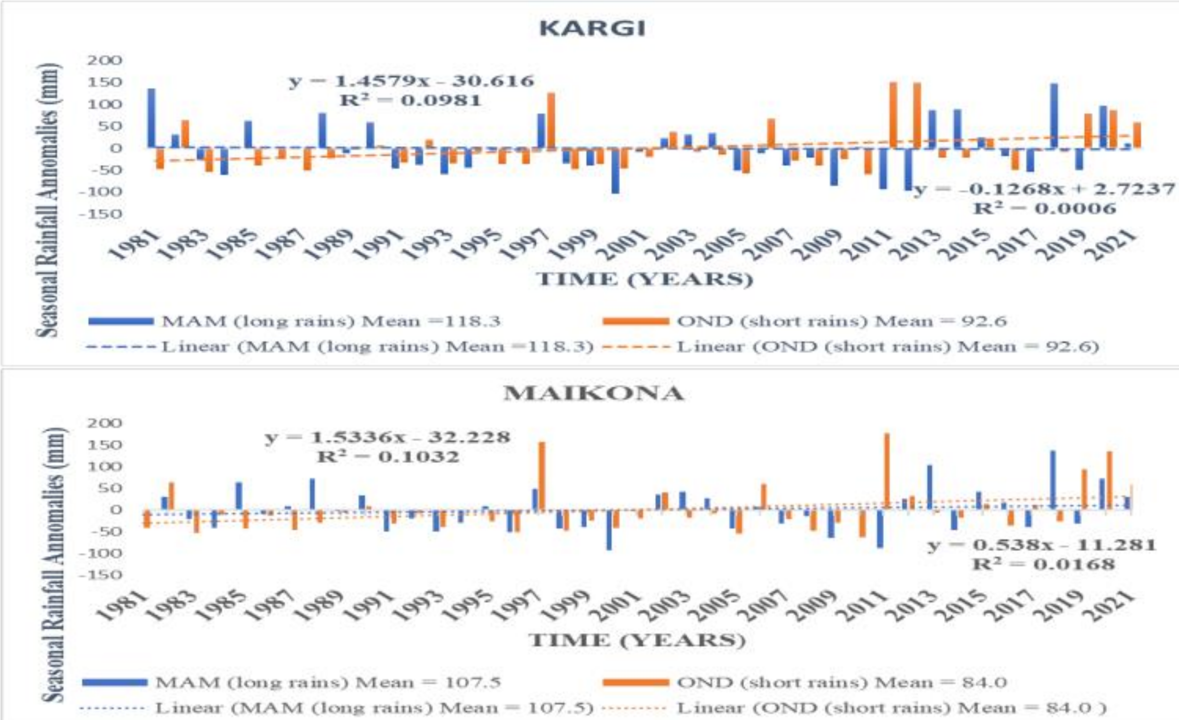

Figure 8. Seasonal rainfall (mm) variations for Kargi, and Maikona wards of Marsabit County (1981–2021).

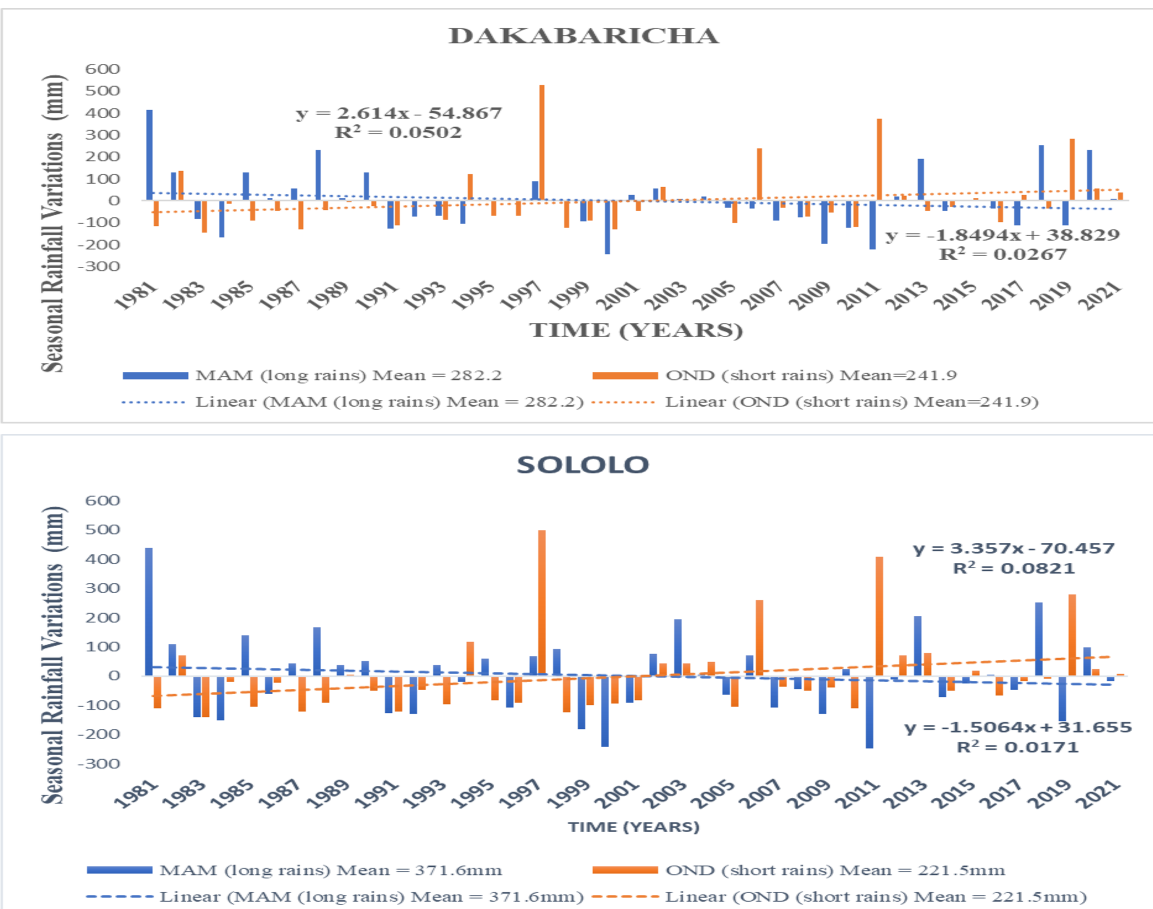

Figure 9. Seasonal Rainfall (mm) Variations for Kargi, Maikona, Dakabaricha, and Sololo wards of Marsabit County.

agriculture, which is what this study found. According to scientists, ASALs will experience more intense rainfall in the long run (Susilo et al., 2013; Avila *et al.*, 2016). Extreme weather events will encourage smallholder farmers to adopt current agricultural production methods and productivity-boosting innovations. According to Susilo *et al.* (2013), the shift in rainfall trend caused by El Niño and La Niña has been debated by many scholars worldwide, implying that ENSO is the most substantial factor causing global hydroclimate variability. As a result, the research lends credence to Susilo's work. Other factors that affected the seasonal variability of rainfall over the study region can be pointed out in Madden Julian Oscillations (Ochieng *et al.*, 2023).

According to Muhati *et al.* (2018a), trends in Marsabit show reduced rainfall with high variability from 1961 to 2014. Funk *et al.* (2010) further found a drastic decrease in crop production due to reduced spatio-temporal rainfall distribution in Kenya. In pastoral and agro-pastoral areas, livestock production and crop yield are affected by changes in seasonal rainfall and extreme events. This makes households vulnerable to climate variability. Furthermore, a study carried out in Kenya's Great Rift Valley found that annual rainfall has decreased, with significant variations across the seasons (Wakachala *et al.*, 2015), affecting production and farmer decision-making.
The study reveals a general decrease in MAM seasonal rainfall in all the study sites except Maikona. These results are consistent with those of other present-day research that examined rainfall patterns over a wider domain and found a general decline in MAM rainfall (Cook and Vizy 2013, Ongoma and Chen 2017). The general rainfall trend over Kenya is declining despite the fact that the OND rainfall indicates a positive trend (Ongoma and Chen 2017), as MAM significantly influences the total rainfall observed in the entire country. Since most agricultural operations depend on MAM rainfall over Kenya, the decrease is projected to have a negative impact on Marsabit County's economic performance, which, if understood, would be an alleviation for the county's economy.

Temperature Trends

Annual Maximum, Minimum, and Mean Temperature Trend for Drier Areas

Figure 10 illustrates the results of yearly average temperature variability and trend in Marsabit County. The highest temperature was 29.8 °C in the Maikona ward in 2021 and 28.0 °C in the Kargi ward in 2017. Analysis of annual temperature trends showed that both night and day temperatures have significantly increased over the years in Kargi and Maikona. The analysis of annual trends and variability of temperatures showed that both above average and below average temperatures have been experienced. The magnitude of warming was found to be double that of cooling in Maikona, with 2021 and 1985 experiencing

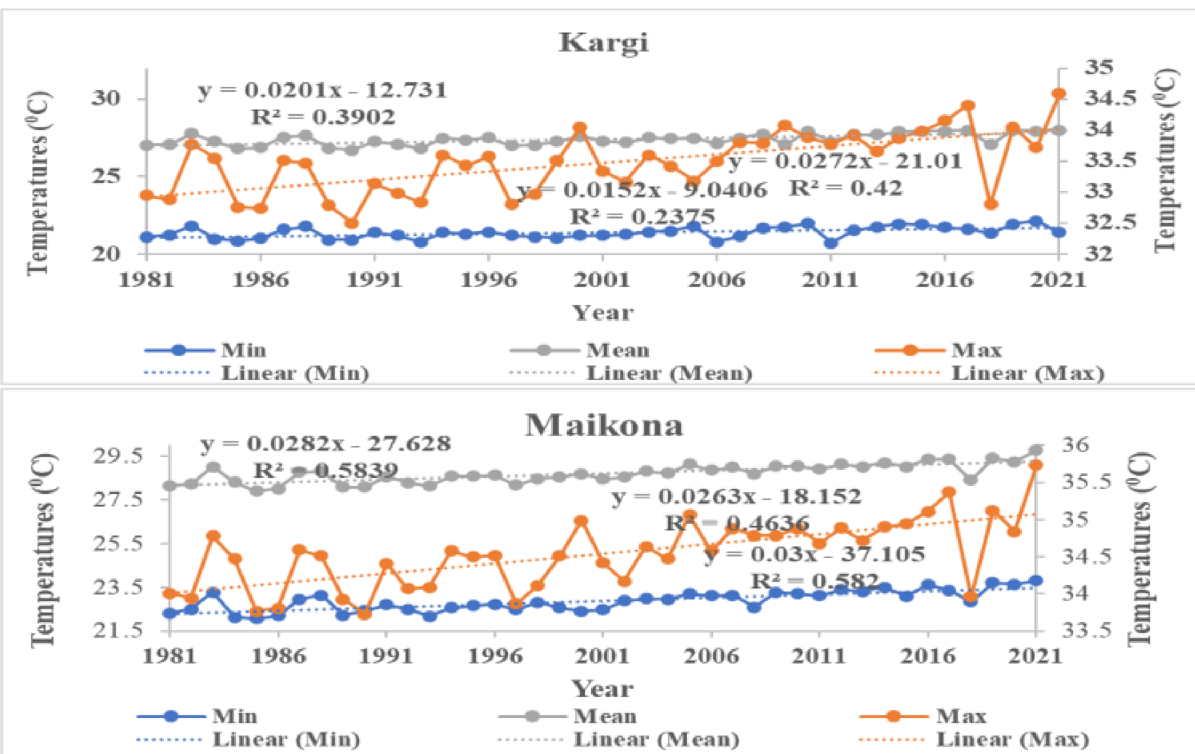

Figure 10. Annual temperature variability in the dry study sites of Kargi and Maikona.

the highest deviation from the mean of 0.62 °C and -0.36 °C, respectively. In the Maikona region, the years 2017 and 2021 experienced above average temperatures, while 1985, 1986, 1989, 1990, and 1993 had below average temperatures. The magnitude of warming in Kargi was found to be slightly lower than that of cooling, with 2017 and 1990 experiencing the highest deviation from the mean of 0.23 °C and -0.3 °C, respectively. The years 2015, 2017, 2019, 2020, and 2021 experienced above average temperatures, while 1985, 1986, 1990, and 1993 had below average temperatures in the Kargi region. (Fig. 9). Kenya experienced severe droughts in 1987, 2000, and 2009, and temperatures were likely to be high during these years. Seasonal temperature changes interfere with the growing, planting, and harvesting times for agricultural production (Mark *et al.,* 2008). The peak range of maximum temperature was received in Maikona at 35.7 °C in the year 2021 (Fig. 10). The trend line equation points out that in the last forty years, Marsabit County has experienced a slightly gradual increase in annual maximum temperatures, as depicted by the gradient of the trend line equations; 0.027 °C and 0.026 °C in Kargi and Maikona, respectively.

The results further indicate that the mean average temperature had an enormously increasing trend, at a mean rate of 0.033 $°Cyr^{-1}$ (1.31 °C in 40 years), 0.046 °C yr^{-1}(1.85 °C in 40 years), 0.079 °C yr^{-1}(3.17 °C in 40 years), and 0.050°C yr^{-1} (2.01 °C 40 in years) in Kargi, Maikona, Sololo, and Dakabaricha, respectively, which is much higher than the worldwide mean temperature rate of 0.0074 °C yr^{-1} (0.74 °C in 100 years). The study findings also show that the temperature is generally rising in the study areas, with maximum temperatures rising at rates of 0.052 $°Cyr^{-1}$, 0.50 $°Cyr^{-1}$, 0.057 $°Cyr^{-1}$, and 0.109 $°Cyr^{-1}$ in Kargi, Maikona, Dakabaricha, and Sololo, respectively, which is consistent with the IPCC temperature projections for eastern Africa (Christensen *et al.,* 2007). Between 1981 and 2021, the annual mean minimum temperatures for Marsabit County were 21.4 °C in Kargi, 22.9 °C in Maikona, 17.5 °C in Sololo, and 20.3 °C in Dakabaricha. The lowest range of minimum temperatures recorded in Sololo, Dakabaricha, Kargi, and Maikona was 16.8 °C in 1985, 19.6 °C in 1993, 20.7 °C in 2011, and 22.1 °C in 1985, respectively. In contrast, the highest range of minimum temperatures recorded in 2021 and 2020 was 23.8 °C in Maikona, 22.1 °C in Kargi, 21.5 °C in Dakabaricha, and 18.9 °C in Sololo (Fig. 5). The trend line equation shows that the minimum temperature in Marsabit County has gradually increased by 0.015 °C yr^{-1}, 0.03 °C yr^{-1}, 0.024 °C yr^{-1}, and 0.028 °C yr^{-1} in Kargi, Maikona, Dakabaricha, and Sololo, respectively. Similarly, mean minimum temperatures in the study region are increasing at a rate of 0.036 °C yr^{-1}, 0.044 °C yr^{-1}, 0.048 °C yr^{-1}, and 0.054 °C yr^{-1} (Kargi, Maikona, Dakabaricha, and Sololo). However, the maximum and minimum temperature trends in the four study wards of Marsabit County (Kargi, Maikona, Dakabaricha, and Sololo) also show variations over the 40-year study period from 1981 to 2021. This means that if the temperature increases at the same rate in Marsabit County, then, in the long run, the county may face an approximately 2- to 3-degree hotter climate relative to the current condition. The WMO (2019) report shows that the years from 2010 to 2019 were warmer compared to the 1980s records. Table 5 is a summary of the trends and variability of temperature in the drier regions of the study from Figure 9.

Annual Maximum, Minimum, and Mean Temperature Trend for Wetter Areas

Analysis of temperature trends for the wetter region of the study showed that both night and day temperatures have significantly increased over the years in Sololo and Dakabaricha (Fig. 11). The magnitude of warming in Dakabaricha and Sololo was found to be double that of cooling, with 2021 and 1990 experiencing the highest deviation from the mean of 0.73 °C and -0.37 °C, respectively, in Dakabaricha, while 2021 and 1986 experienced the highest deviation from the mean of 1.368 °C and -0.58 °C, respectively, in Sololo. The years 2017 and 2021 experienced above average temperatures, while 1986 and 1990 had below average temperatures in Sololo, and the year 2021 experienced above average temperatures, with the years 1985, 1986, 1989, 1990, 1991, and 1993 experiencing below average temperatures in Dakabaricha. The results show that the average annual temperature in the area has been constantly increasing over the past 40 years. Marsabit County's lowest average temperature was 22.5 °C in the Sololo ward in 1986 and 25.50 °C in the Dakabaricha ward in 1990. The lowest range of maximum average temperature in the past 40 years in Marsabit County was recorded at 28.1 °C in Sololo ward in 1986. The wetter locations experienced a gradual increase in annual maximum temperatures as depicted by the gradient of the trend line equations of 0.024 °C and 0.051 °C in Dakabaricha, and Sololo, respectively. It's not clear what may have caused the sudden rise in temperatures; however, one of the likely causes is anthropogenic (human) activities such as poor farming technologies and land use (Muhati et al., 2018), which may lead to the emission of excessive greenhouse gases into the atmosphere, raising the study area's temperatures and causing climate change (IPPC AR6, 2022). The phenomenon has triggered additional changes in global climatic systems, such as precipitation shifts. Observational climatic data from weather stations on the earth's surface show dramatic changes in climate over the last two million years. Other studies in different parts of the region (Niang et al., 2014; Adhikari et al., 2015; Camberlin, 2017) found the same increasing trends in temperature, but the magnitude varied depending on the type of data. In addition to the mean change in maximum and minimum temperatures, East Africa has significantly increased temperature extremes (Gebrechorkos et al., 2018).

Table 6 provides a summary of the temperature trends and variability in the wetter locations of Dakabaricha and Sololo. Dakabaricha is hotter than Sololo. However, there is a higher rise in temperatures in Sololo, which should be mitigated.

The study's findings concur with those of Tsige (2018), who reported steadily increasing minimum and maximum temperatures in the Sidama Zone of southern Ethiopia from 1987 to 2017. In addition, Asfaw et al. (2018) discovered that the mean maximum and minimum annual temperatures increased by 0.067 °C and 0.026 °C every ten years, respectively (between 1901 and 2014). The findings of this research agree with those of Huq *et al.* (2003), who found that temperatures rise during the monsoon season, with the highest and lowest temperatures going up by 0.05 °C and 0.03 °C per year, respectively, in least-developed countries. The reported rise in mean, maximum, and minimum temperatures is a sign that more extreme events are likely to take place. Despite a slight variation in mean temperature, the number of cold and warm days can be significantly impacted. In general, the findings point to a persistent rise in the average surface temperature across all survey stations. In comparison to low-elevation areas, the observed temperature rise is greater in high-elevation areas.

Temperature Variability

Yearly Average Temperature Variations in Drier Areas (Pastoral)

Figure 12 depicts the annual average temperature variability from long-term means for drier sites studied in Marsabit County from 1981 to 2021. The mean temperatures increased in Kargi from 26.7 °C (1990) - 28.0 °C (2017) and in Maikona from 27.9 °C (1985) - 29.8 °C (2021). The years with the highest average temperature anomalies were 1985 (-0.6 °C), 1990 (-0.7 °C), 2017 (+0.61 °C), and 2021 (+0.59 °C) in Kargi; 1985 (-0.8 °C), 1986 (-0.7 °C); 2019 (+0.71 °C); and 2021 (+1.06 °C) in Maikona. The findings of this research corroborate with Gebrechorkos's (2019) study, which discovered that some regions in Kenya, Ethiopia, and Tanzania lack clear patterns of precipitation indices due to rainfall variability caused primarily by local factors rather than large-scale factors. By the end of the twenty-first century, the Intergovernmental Panel on Climate Change (Climate Change, 2021) reported almost the same rise in temperature (2.6-4.8 °C) for the globe, a 3-4 °C rise by Collins (2011) over Africa, and a 1.6 -

Table 5. Trends and variability of Temperature in the drier (Pastoral) regions of the study.

Study region	Warmest years	Increase	Coolest years	Increase	Above average years from the mean	Below average years from the mean
Kargi	2017	0.23	1990	-0.3	2015	1985
					2017	1986
					2019	1990
					2020	1993
					2021	
Maikona	2021	0.618	1985	-0.36	2017	1985
					2021	1986
						1989
						1990
						1993

Table 6. Trends and variability of Temperature in wetter (Agro-pastoral) regions of the study.

Study region	Warmest years	Increase	Coolest years	Increase	Above average years from the mean	Below average years from the mean
Sololo	2021	1.368	1986	-0.58	2017	1986
					2021	1990
Dakabaricha	2021	0.73	1990	-0.37		1985
					2021	1986
						1989
						1990
						1991
						1993

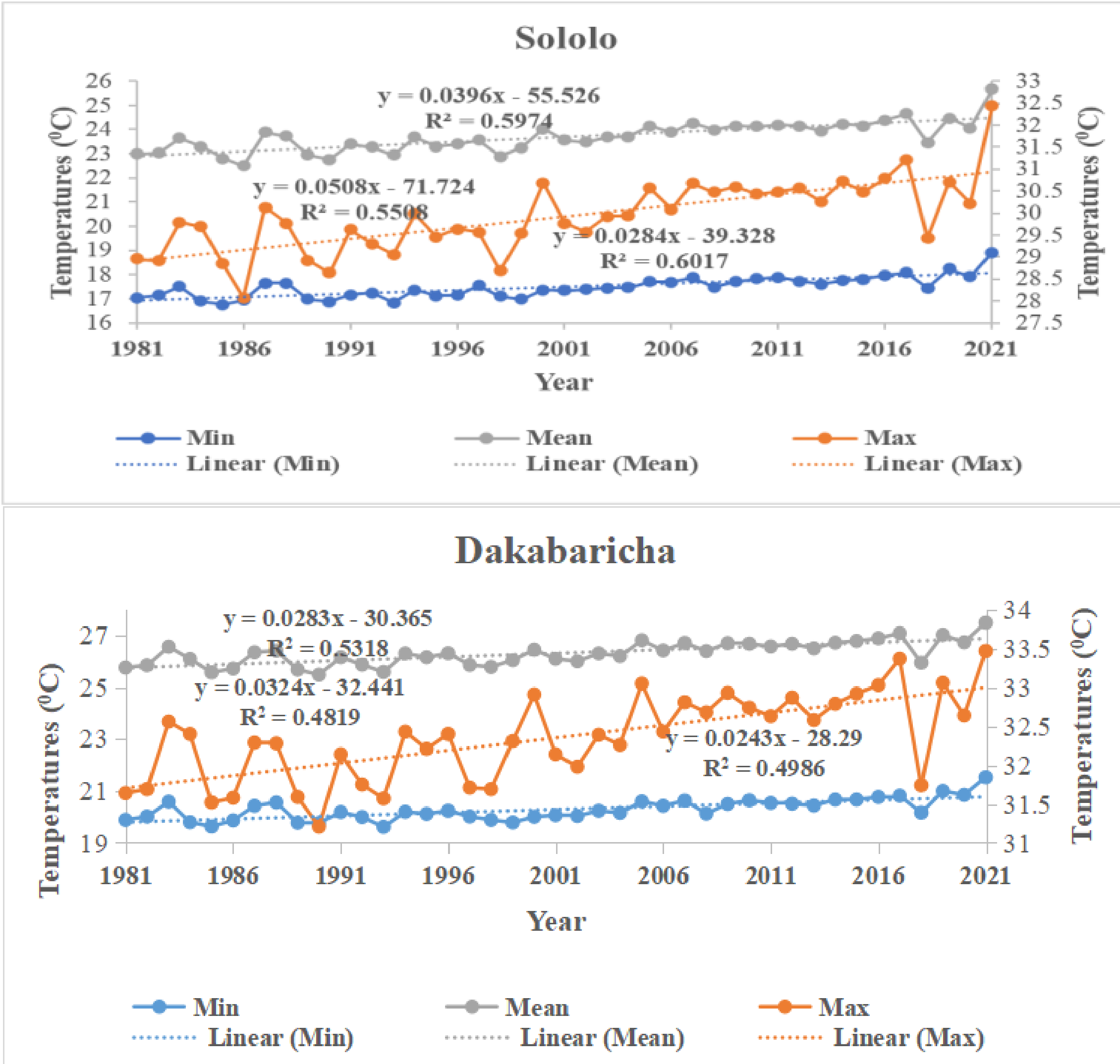

Figure 11. Annual temperature variability in the dry study sites of Sololo and Dakabaricha.

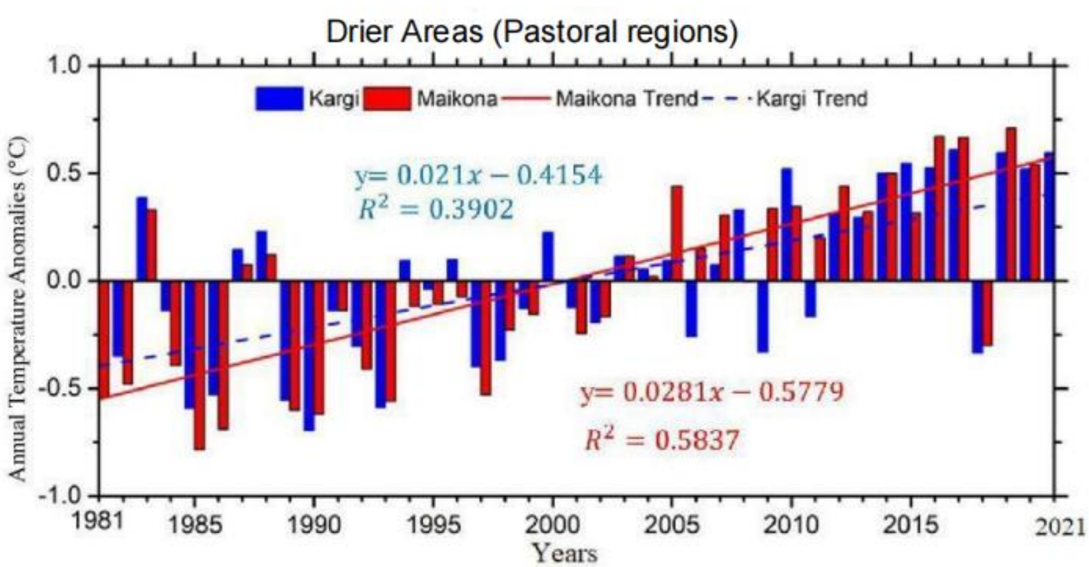

Figure 12. Annual Average Temperature Variations for Kargi and Maikona wards of Marsabit County from 1981 to 2021.

6 °C increase by Sylla *et al.* (2016) in West Africa. With 95% certainty, the IPCC's Sixth Assessment Report confirms that rising levels of GHG in the environment have been the leading cause of heating since 1950 (Climate Change, 2021).

Yearly Average Temperature Variations in Wetter Areas (Agro-pastoral)

Average yearly temperature variability in Sololo ranged from 22.5 °C (1986) -25.7 °C (2021), and in Dakabaricha from 25.5 °C (1990) -27.5 °C (2021). The highest temperatures in the wetter areas were as follows; 1985 (-0.9 °C), 1986 (-1.2 °C), 2017 (+0.96 °C), 2021 (+1.98 °C) in Sololo, and 1985(-0.7 °C), 1990(- 0.8 °C), 2017 (+0.80 °C), and 2021 (+1.20 °C) in Dakabaricha (Fig. 13). Despite contributing the least GHG gases to the atmosphere, global warming has affected the African continent the most, with an average emission of 1 metric ton of greenhouse gases (Fields, 2005). Temperature increases in the study region can strain water resources, reduce crop productivity, reduce livestock production, jeopardize food security, and increase human and livestock diseases. The average temperature in most parts of Africa has risen by more than 0.5 °C in the past fifty to a hundred years (Niang et al., 2014; CDKN, 2014; Nicholson et al., 2014). According to Gan et al. (2016), global warming has increased by 0.72 °C and is expected to continue into the twenty-first century (Gebrechorkos et al., 2019).

Yearly Mean Maximum and Minimum Temperature Anomalies in Drier Areas (Pastoral)

The average maximum and minimum temperatures vary significantly in the study regions from 1981 to 2021, as shown in Figure 14. Considering the drier regions, results indicate that the highest maximum temperature variations in the study region were: 1986 (-0.7 °C), 1990 (-0.9 °C), 2017 (+0.93 °C), and 2021 (+1.12 °C) in Kargi; 1986 (-0.77 °C), 1990 (-0.81 °C), 2017 (+0.83 °C), and 2021 (+1.19 °C) in Maikona. Varying average minimum temperatures were received in the years; 2011 (-0.68 °C) and 2020 (+0.74 °C) in Kargi, 1985 (-0.82 °C) and 2021 (+0.92 °C) in Maikona.

Yearly Mean Maximum and Minimum Temperature Anomalies in Wetter Areas (Agro-pastoral)

Comparatively, the wetter locations recorded the maximum temperatures of 1985 (-0.83 °C), 1990 (-1.14 °C), 2017 (+1.02 °C), and 2021 (+1.12 °C) in Dakabaricha and 1986 (-1.84 °C), 1990 (-1.28 °C), 2017 (+1.3 °C), and 2021 (+2.52 °C) in Sololo. The minimum variations were recorded in 1993 (-0.67 °C) and 2021 (+1.24 °C) in Dakabaricha and 1985 (-0.71 °C) and 2021 (+1.43 °C) in Sololo (Fig. 15). The IPCC predicted that global temperatures would rise by 0.3 °C to 0.7 °C over the next two decades, with increases of 0.3 °C to 0.48 °C by the end of the twenty-first century (Adhikari et al., 2015). Temperature increases will likely change how much it rains, how often it rains, and how hot it is worldwide. These changes are likely to be accompanied by an increase in drought events. High projections of 0.14 to 5.8 °C per decade were established, with crop yield reductions ranging from 11 to 46% by 2050. (Liu et al., 2018).

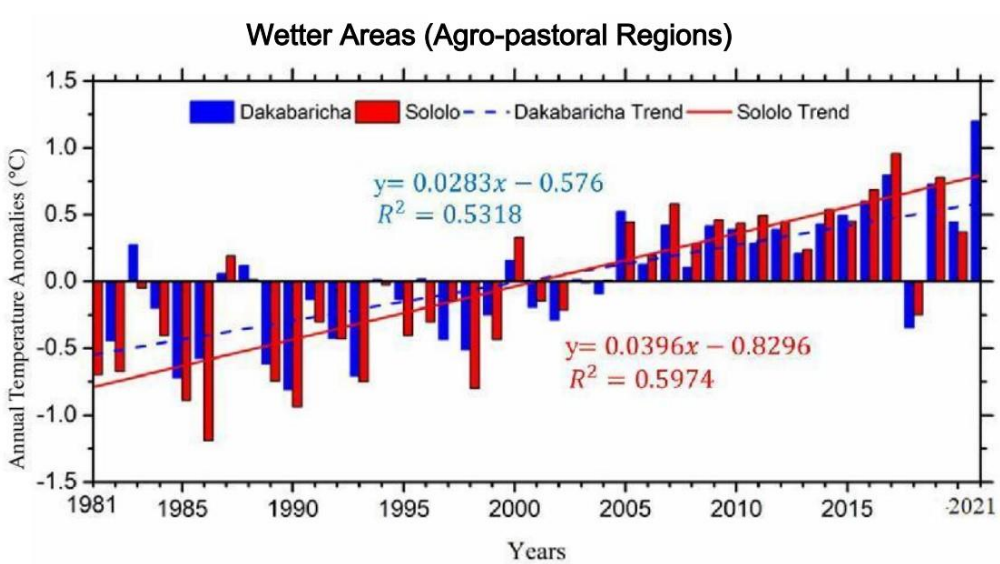

Figure 13. Annual average temperature variations for Dakabaricha, and Sololo wards of Marsabit County from 1981 to 2021.

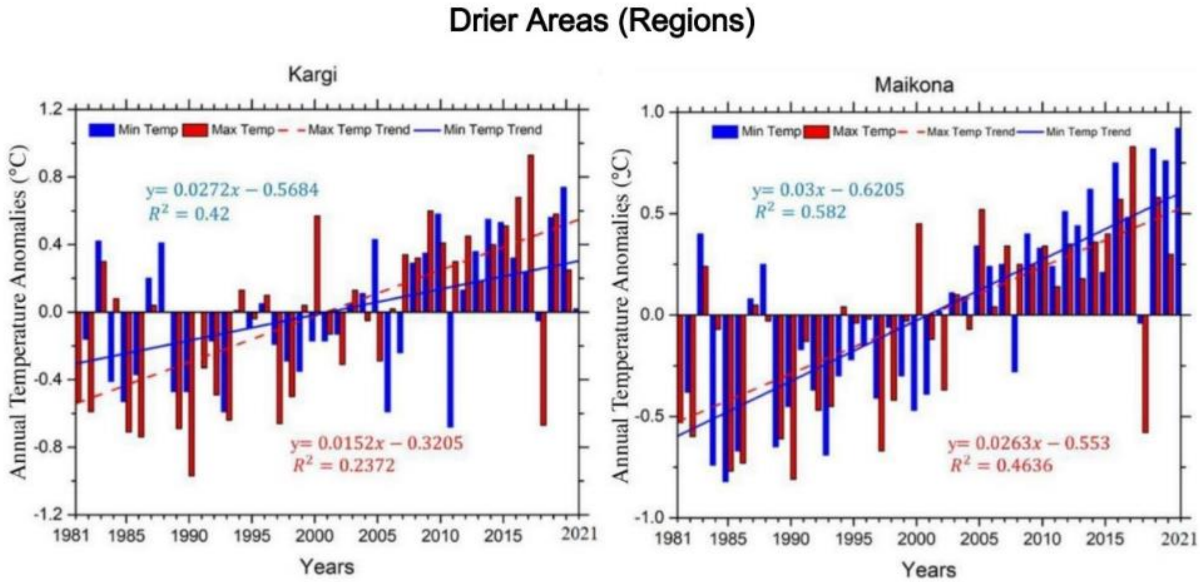

Figure 14. Annual average (Max. and Min.) temperature variations for Kargi and Maikona wards of Marsabit County (1981 - 2021).

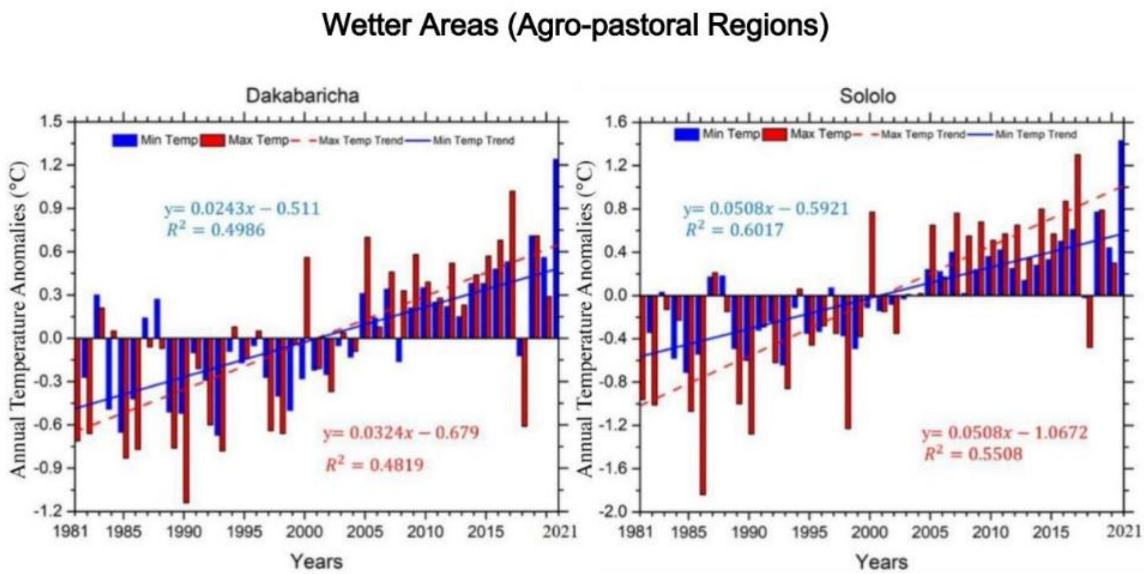

Figure 15. Annual average (Max. and Min.) temperature variations for Dakabaricha, and Sololo wards of Marsabit County (1981 - 2021).

Kenya has a severe problem with frequent droughts in different places, significantly affecting crop production and yields. The most worrying thing is that droughts will likely worsen, greatly affecting food crop production in the study region. Kinh'Uyu *et al.* (2000) examined how the minimum and maximum surface temperatures in Eastern Africa changed over time. Their results show that the region has changed. In recent years, the northern part of Eastern Africa has been warming at night while the southern part has been cooling. In many parts of the study area, maximum and minimum temperatures increase as rainfall decreases. This causes more evaporation and more severe droughts.

Regression analysis between Precipitation (PPT) and Temperature (Tmean)

Figure 16 demonstrates the results of the regression analysis performed on Precipitation against Temperatures in Marsabit County. The Pearson’s Chi-square test performed on Precipitation against Temperatures gave P values far less than 0.05, as shown in the results, which meant that there existed a significant relationship between air temperatures and

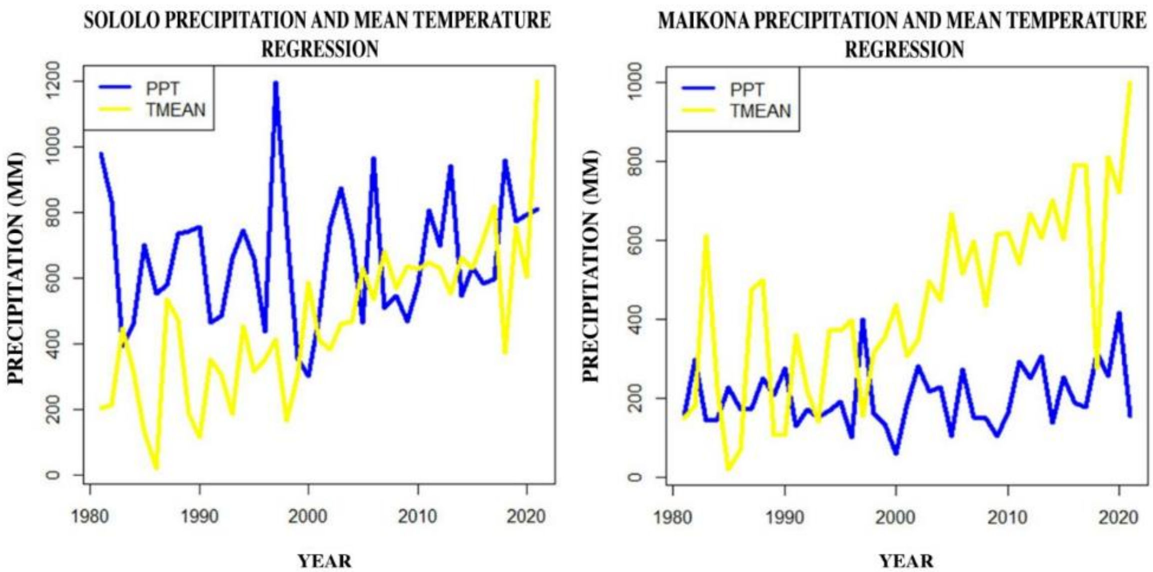

Figure 16. Regression analysis between temperature (TMEAN) and precipitation (PPT) in Sololo (Wetter) and Maikona (drier).

precipitation in Marsabit. Similarly, the regression analysis done on rainfall and temperatures in Kargi, Sololo, Dakabaricha, and Maikona showed that air temperatures affect precipitation. The study indicates that there exists a negative correlation between temperatures and rainfall, as indicated by the negative coefficients, implying that rainfall decreases with increasing temperatures in Marsabit County. The coefficient of variability was highest in Dakabaricha, which recorded -82.93 while Kargi, Sololo, and Maikona recorded -28.4, -13.03, and -10.44 respectively, implying that temperatures had a greater effect on rainfall in Dakabaricha as compared to the rest of the county. Years with the lowest rainfall, such as 2000, had higher temperatures, while years with the highest rainfall, such as 1990 and 1997, had lower temperatures. This gives the reason behind decreasing rainfall trends during the long rainy season MAM as temperatures increase with the years.

Correlation Analysis

Correlations of Annual Rainfall, Maximum Annual Temperature, and Minimum Annual Temperature for Marsabit County

The Pearson correlation results for annual mean rainfall and maximum and minimum temperatures from 1981 to 2021 are shown in Tables 7 and 8. Annual rainfall had a statistically significant ($p = 0.01$) negative correlation with maximum temperature (Kargi $r = -0.331$, $p = 0.035$, Sololo $r = -0.356$, $p = 0.022$). The negative sign indicates that the variables are inversely related or change in opposite directions over time. Furthermore, the study's findings show that

Table 7. Correlations between Annual Rainfall, Maximum and Minimum Temperature for Kargi and Maikona region.

Variable	KARGI			MAIKONA		
	Rainfall (mm)	T_{Max} (°C)	T_{Min} (°C)	Rainfall (mm)	T_{Max} (°C)	T_{Min} (°C)
Rainfall	1	-0.331*	0.016	1	-0.266	0.152
Maximum Temperature (°C)	-0.331*	1		-0.266	1	
Minimum Temperature (°C)	0.016	0.559**	1	0.152	0.787**	1

*. Correlation is significant at 0.05 level (2-tailed).
**. Correlation is significant at 0.01 level (2-tailed).
**. Correlation is significant at 0.01 level (2-tailed).
N = 40

Table 8. Correlations between Annual Rainfall, Maximum and Minimum Temperatures for Dakabaricha and Sololo region.

Variable	DAKABARICHA Rainfall (mm)	T_{Max} (°C)	T_{Min} (°C)	SOLOLO Rainfall (mm)	T_{Max} (°C)	T_{Min} (°C)
Rainfall	1	-0.131	0.129	1	-0.356*	0.013
Maximum Temperature (°C)	-0.131	1		-0.356* (0.022)	1	
Minimum Temperature (°C)	0.129	0.892**	1	0.013	0.835**	1

*. Correlation is significant at 0.05 level (2-tailed).
**. Correlation is significant at 0.01 level (2-tailed).
N = 40

annual rainfall has a significantly strong and positive correlation with maximum temperature in Maikona and Dakabaricha (Maikona r = 0.787, p = 0.000, Dakabaricha r = 0.892, p = 0.000), implying that the two climate variables move in the same direction during the same season. The study also found a weak and positive correlation between annual rainfall and minimum temperature (Kargi r = 0.016, p = 0.920, Maikona r = 0.152, p = 0.034; Dakabaricha r = 0.129, p = 0.421; Sololo r = 0.013, p = 0.0936) that was not statistically significant (p = 0.01). A positive sign indicates that as the value of one variable rises, the value of the second variable also rises. Previous research by Camberlin et al. (2001) found a strong link between OND's short rainy season and the highest temperatures in the area. This study's results are in line with those of Collins (2011), who discovered that variability in the El Niño-Southern Oscillation is most likely not causing climate change over Eastern Africa. Instead, climate change is more likely due to other natural variability in the climate or anthropogenic activities.

Recommendation

Based on the present study,the following recommendations are made:

1. The reduction in the seasonal and annual rainfall totals experienced in some locations should trigger the agricultural and livestock sectors to come up with animal and crop varieties that can withstand the temperatures and rainfall amounts. This will ensure food and nutrition security in the County
2. The meteorological network should be improved to ensure proper monitoring and observations. The data can be of use in tracking the temperature and rainfall trends at very high resolution for modeling and research purposes. The variations in the anomalies should be dynamically evaluated to determine the underlying local and mesoscale features that affect the temperature and rainfall variabilities over the study area.
3. This study recommends use of rainwater harvesting during OND Season to take advantage of the increasing OND Trends and flood episodes associated with high magnitudes and frequencies of above average rainfall during OND and use the same to cope with reduced rainfall in MAM. The study greatly advocates for increased tree cover to cope with and mitigate the warming, enhance groundwater recharge, and control floods.
4. The study's findings will be useful to research institutions, academia, and county and national governments in organizing and handling water resources on a seasonal and yearly basis, as well as policymakers in providing relevant adjustments and control measures to withstand expected weather risks in the study region. Overall, based on the research findings, the region requires special consideration in coming up with long-term adaptation strategies, such as the construction of water harvesting dams, to mitigate impacts such as those on livelihoods. Furthermore, the study's results may aid policymakers in determining key areas for implementing adaptation approaches.

CONCLUSION

The effects of climate change manifest themselves in the form of extreme climate events, whose indicators are mainly high temperatures and precipitation events. The present study aimed to examine the temporal variability of temperature and rainfall trends in four wards of Marsabit County, Kenya, in the past four decades (1981-2021). This study concludes the following:

1. Results on rainfall trends and variability show that both pastoral (Kargi and Maikona) and agro-pastoral (Dakabaricha and Sololo) areas of

Marsabit County have been experiencing increasing trends of rainfall from 1981 to 2021.

2. Seasonal rainfall has decreased, annual rainfall totals for the long rains (MAM) are increasing, and both the maximum and minimum temperatures have gradually increased.
3. Annual rainfall amounts in the study region have significantly remained constant, with the exception of a slight increase due to a rise in short rains (OND) in some areas.
4. The results show that annual rainfall has a significant negative relationship with maximum temperature in Kargi and Sololo. In contrast, annual rainfall had a significant and positive correlation with minimum temperature in the entire study region.
5. The temperature trends and variability analysis showed that the temperatures have increased with no significant change. Both nighttime and daytime temperatures have been rising over the years in Marsabit County.
6. A significant relationship existed between air temperatures and precipitation in Marsabit. Similarly, analysis done on rainfall and temperatures in Kargi, Sololo, Dakabaricha, and Maikona showed that air temperatures affect precipitation.

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Conflicts of interest The authors declare no conflicts of interest.

Compliance with ethical standards. The study involves the use of household survey and satellite meteorological data obtained from Climate Hazards Group Infra Red Precipitation with Station, gridded at a resolution of 0.05^0x 0.05^0 (approximately 5 km x 5 km over land), and daily temperature information obtained from the European Centre for Medium Range Weather Forecasts Re-Analysis, ERA5. Permission to conduct the study was sought from the National Commission for Science, Technology, and Innovation (NACOSTI) via a formal subscription fee to conduct the study in the area. The study upholds anonymity and confidentiality as moral imperatives in all its undertakings. This manuscript contains no violation of any existing copyright or other third party right or any material of an obscene, indecent, libellous, or otherwise unlawful nature, and to the best of their knowledge, the manuscript does not infringe the rights of others.

Data availability. The data used to analyze this research is available upon reasonable request from the corresponding author (*agalwab@gmail.com*).

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