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Climate Trends and Their Impact on Sorghum Production in Marigat, Baringo County: A Historical Analysis

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Abstract

Climate is subject to fluctuations in the majority of the world, mainly caused by rainfall as well as temperature variations. Climate fluctuations in Kenya have resulted in the spread of desert-like conditions in the ASALs region, such as Marigat in Baringo County. As a county, Baringo experiences great variations in climate annually, as well as uncertainty in expected rains, thereby negatively impacting the production of crops such as sorghum. This study applied the rainfall anomaly index (RAI), standardised precipitation evapotranspiration index (SPEI), standard precipitation index (SPI), and Mann-Kendall (MK) statistical test for trends on historical climatic data in analysing both temperature and precipitation data over the period 1990 to 2022 to determine their trend, patterns and how they affect the production of sorghum crops. The machine learning method (R studio) with inputs was used to calculate the SPI, SPEI, RAI and MK trend test. The rainfall varied from below average to above average during the study period with no clear pattern in the RAI, SPEI and SPI values. The years 2020 and 2000 stood out as they had higher and lower rainfall than usual, respectively. The Marigat area generally experienced more rainfall during the high/long rainfall season (AMJJ). The MK trend test on average monthly rainfall, SOND, AMJJ, and annual precipitation confirmed a positive trend in precipitation. However, the short rainy season (SOND) was found to be the most variable period for rainfall, and there was a slight increase in daily average temperatures during this season.

Keywords

Trends, Precipitation, Temperature, RAI, SPI, SPEI, and MK

1. Introduction

Changes in precipitation, including frequency, intensity, and overall amount, are occurring worldwide due to climate change [1]. Both rainfall and temperature play a critical role in determining the climate of a particular area [2]. Categorisation of the world's climate is based on two major elements that are rainfall and temperature. Precipitation patterns are caused by rainfall variability, which refers to the degree of variance in rainfall amounts within an area over a given period [3]. This variation, when recorded at various locations in a specific area, is called the real variability. However, when this variation is recorded in only one particular place for a given period of time, it is called temporal variability. Variability in both temperature and rainfall is a global problem because it disrupts farming activities in most areas of the world [4]. Ultimately, variability negatively impacts livestock and crop production. In the majority of marginal as well as ASALs regions, the variability problem is more serious, which leads to the loss of crops in places like Marigat in Baringo County [5]. To understand the impact of climate on sorghum production in Marigat, it is important to analyse historical climatic data and identify trends in temperature and precipitation patterns. Historically, Marigat and the surrounding areas have experienced arid and semi-arid climates, with average rainfall of 450 - 700 mm and a mean temperature of around 25˚C. However, there have been reports of climatic changes, including increased flooding events, in the past four decades according to local pastoralists' indigenous knowledge. Marigat experiences a diverse climate characterised by unique erratic rainfall patterns and temperature variations. These variations profoundly influence the agricultural landscape, thereby affecting sorghum cultivation. The available sources also highlight the variation in rainfall patterns, with about 60% of the total annual rainfall occurring between April and August. This variation in rainfall patterns, coupled with the recent increase in heavy rainfall and flooding events, suggests that there may be a changing climate trend in Marigat [6].

Rainfall in the majority of the world is subject to uncertainty and variability due to fluctuations. The main cause of this variability is climate change. In Marigat, the high temperature increases evaporation in the region, making it dry for a better part of the year. Therefore, it is necessary to understand the patterns of both precipitation and temperature to determine how they affect the production of sorghum, as well as other crops. The rainfall distribution in Marigat is uneven because some areas experience higher precipitation than others. This variability across various parts of Baringocounty tends to contribute to disparities in soil moisture, thereby affecting the yield and growth of sorghum. This is because the majority of areas in the region receiving insufficient rainfall tend to face water scarcity, which in turn affects crop development. The effects of rainfall variability on sorghum crop cultivation are multifaceted [5]. This is because insufficient or erratic rainfall affects the soil moisture, which is necessary for seed germination and plant growth.

Over the years, the frequency of extreme weather conditions, such as intense storms and prolonged droughts, has also increased in the Marigat region. These extremities disrupt agricultural activities because they cause erosion of the soil, damage to crops, and arable land loss. Therefore, the majority of farmers face challenges in adapting their farming practices to mitigate the risks associated with these extremities [3]. The negative impacts of variations in temperature and precipitation on sorghum production in Marigat underscore the urgent need for adaptive strategies.

Sorghum production in Marigat is extremely intertwined with the climatic conditions of the region. Historical trends in both temperature and precipitation patterns reflect land characterised by an increased rise in temperature, as well as an unpredictable distribution of rainfall. It is prudent for farmers to understand these climatic conditions for the purpose of devising sustainable strategies aimed at enhancing the resilience of sorghum with respect to ever-changing conditions. This section looks at previous studies conducted by scholars on historical climatic data and how these conditions affect the production of sorghum as well as other crops in the Marigat region. Projections for sub-Sahara African countries like Kenya indicate that a warming rate exceeding 3˚C could render most of the present sorghum farmlands unviable, leading to increased economic costs and uncertainty [7]. The purpose of the study was to investigate the long-term climate trends in Marigat, Baringo County, and their potential influence on sorghum production. By conducting a historical analysis, the study aimed to identify patterns and changes in climate variables such as temperature, and precipitation. The study also pursues to assess how these climate trends correlate with the productivity and yield of sorghum in the region.

1.1. Historical Climatic Trends in Marigat

The Marigat region traditionally has two rainy seasons; however, the rainfall pattern is always uneven. This uneven pattern creates numerous challenges for farmers who cultivate sorghum in the area. For many years, Marigat has been experiencing a bimodal rainfall distribution, that is, two rainy seasons and intermittent dry seasons. A long rainy season occurs from March to May, whereas intermittent short rains occur in September, October, November, and December. However, historical data tends to reveal variability and unpredictable patterns in rainfall occurrence. These irregularities have become increasingly common, thereby negatively affecting crop growth and farming schedules [8]. The irregular onset of rain in the region often delays sorghum planting, thereby affecting synchronised sorghum growth cycles. Similarly, unpredicted rain cessation can equally reduce the growing period and available optimal crop development time [9]. Therefore, the planning and execution of sorghum cultivation in this area is challenging for farmers.

Prolonged dry spells are common in the Marigat region and are interspersed during rainy seasons. These prolonged dry spells cause inadequate moisture content in the soil, which hinders seed germination and early plant growth. Sorghum being a drought-tolerant crop tends to face stunted growth and diminishing yield during these challenging periods [10]. In addition, prolonged dry spells tend to cause an uneven distribution of moisture in the region. Some areas in the region often receive more rainfall than others. This uneven distribution of rainfall is attributed to disparities in soil moisture, which affects the growth and yield of sorghum crops. Sorghum cultivation is significantly affected by water stress which is regularly experienced in the area. In addition, during flowering, most crops require adequate water to properly fill the grains. Inadequate water at this stage results in smaller yields and reduced grain formation.

1.2. How Temperature and Precipitation Patterns Affect Sorghum Production

Changes in both temperature and precipitation have a great impact on the growth and development of sorghum and other crops in Marigat. In most cases, an increase in temperature and a decrease in precipitation have led to a production shortage in sorghum. However, a decrease in temperature and an increase in precipitation have always boosted sorghum production. As noted by Eggen *et al.* (2019), higher temperatures tend to intensify evapotranspiration rates, thereby increasing the water demand for sorghum. Insufficient water is known to cause stress in plants, making them unhealthy and unproductive [9]. In addition, the potential yield is significantly affected because water stress limits moisture availability. An increase in pests and diseases is also facilitated by high temperatures. For example, in Marigat, increased temperatures have a higher possibility of favouring the proliferation of unique pests, which threatens sorghum crops in the long run. Moreover, temperature fluctuations can create conditions conducive to disease spread, which can further jeopardise the productivity and health of sorghum plants [11].

Sorghum grain yields have been known to decline when the temperature crosses the threshold of 350C. This is because various reproductive stages of sorghum, just like other grains, such as barley, wheat, rice, and maize, appear to be sensitive to abiotic stresses caused by environmental factors. The most drought-sensitive stages for sorghum are the panicle development, grain filling, and flowering stages [8]. Compared to the vegetative stage, the reproductive stage is the most critical because if the stress persists, production will be greatly affected. In sorghum, this reproductive stage occurs between 10 and 5 days before anthesis and after anthesis. Excessive heat during this period can affect floret fertility (*i.e.* which is a factor that determines the number of grains per spike in sorghum), which might result in a poor seed set [5]. Therefore, for every environment, the critical stage of sorghum should coincide with the optimal air temperature and precipitation to realise a potential yield.

Generally, sorghum crops tend to adapt and thrive well when the air is between 15˚C and 40˚C. Stresses due to high temperatures tend to decrease photosynthesis, which is associated with the development of cell structures [12]. When the cell structure is deformed, there is a possibility of damage to the thylakoid membranes, chloroplast-protein complexes, and chloroplast envelope. Moreover, the functional implications of high temperature on photosynthesis include inactivation and inhibition of Calvin-Benson cycle enzymes. This inactivation can lead to structural changes in the grana. As noted by Grossi, Justino, Rodrigues & Andrade (2015), high-temperature stress can also lead to pigment concentration decrease, and damage to electron transport system of the plant. Once the electron transport system is damaged, all photosynthesis-related activities are halted. Sorghum is a crop contains the ribulose 1,5-bisphosphate carboxylase enzyme, which helps to speed up photosynthetic activities. However, the activity of this enzyme is significantly affected at high temperatures. In the long run, the crop may end up drying because it lacks essential nutrients.

The study area is prone to water stress due to fluctuations in precipitation levels. During the rainy season, the moisture level rises steadily; however, in the dry season, this level is adversely affected, leading to stress in the plants [13]. Sorghum crops require approximately 450 - 650 mm of water from planting to maturity. During the early stages of growth, the daily water requirement is approximately 1 mm to 2.5 mm per day. This water threshold is sufficient to avoid crop stress. However, this requirement changes as the crop enters 7-leaf stage. At this stage, the crop requires at least 7 - 10 mm of water per day.

To address this knowledge gap and effectively implement climate-smart adaptation strategies, further research and monitoring of temperature and precipitation patterns in Marigat, Baringo County are necessary [14]. This will enable farmers and policymakers to make informed decisions and develop targeted adaptation interventions that can effectively enhance the resilience of sorghum production in the face of changing climatic conditions [15].

1.3. Climate and Hydrological Analysis Methods

The SPI, SPEI, RAI and Mann-Kendall tests have been used to analyse the trend and pattern of precipitation. Constant investigation into rainfall anomaly pattern is very crucial as it enables the detection of any departure from normal rainfall conditions. The commonly applied climate analysis methods are discussed as follows.

1.3.1. Standardized Precipitation Index (SPI)

The Standardized Precipitation Index is a useful tool for quantifying and analysing precipitation deficiencies. It allows for easy comparison of drought severity across different regions and timeframes. Furthermore, the SPI can be calculated for various time scales, making it adaptable to both short-term and long-term drought assessments [16]. The SPI at different time scales, such as 1-month, 3-month, 6-month, 9-month, and 12-month provides insights into various aspects of moisture conditions and their implications. The 1-month SPI is used to assess short-term soil moisture and crop stress. The 3-month SPI reflects both short- and medium-term moisture conditions. The 6-month SPI is associated with unusual stream flows and reservoir levels. The 9-month SPI provides an indication of precipitation patterns over a medium time scale. Lastly, the 12-month SPI is particularly useful in understanding long-term effects on stream flows, reservoir levels, and even groundwater levels. The SPI at different time scales serves as a valuable tool in understanding precipitation patterns and their impact on soil moisture, drought conditions, stream flows, reservoir levels, and overall water resource management [17]. In order to assess moisture conditions and predict potential impacts on crops and water resources, the Standardized Precipitation Index is a commonly used drought index globally [18]. The SPI values are categorised into various categories that indicates agricultural, meteorological and hydrological droughts as outlined in **Table 1**.

1.3.2. The Standardized Precipitation Evapotranspiration Index (SPEI)

The Standardized Precipitation Evapotranspiration Index is an important tool for monitoring and assessing drought conditions [16]. It takes into account both precipitation and evapotranspiration, providing a comprehensive measure of water availability. This index is particularly useful in studying the effects of global warming on drought and can be used for drought monitoring purposes [16]. The SPEI is able to capture whether periods of drought and how they are influenced by increases in temperature, even when there may not be major changes in rainfall patterns. By incorporating both precipitation and evapotranspiration data, the SPEI offers a more holistic view of drought conditions. [19] calculated the Standardized Precipitation Evapotranspiration Index using the simulated precipitation and evaporation to estimate drought conditions. This approach allowed for better monitoring, analysis, and quantification of drought severity and its impacts. The SPEI's multi-scalar properties enable it to distinguish between different types of droughts and their impacts [20]. The SPEI can provide valuable information for water resources management and decision-making by identifying periods of prolonged drought or extreme wetness. Like SPI, SPEI values are also categorized into various categories that indicates drought and wet levels as outlined in **Table 2**.

Table 1. SPI values for classification of dry/wet severity.

SPI Values	Category
≥2.0	Extremely wet
1.5 to 1.99	Severely wet
1.0 to 1.49	Moderately wet
−0.99 to 0.99	Near normal
−1.0 to −1.49	Moderately dry
−1.5 to −1.99	Severely dry
≤−2	Extremely dry

Source: [16].

Table 2. The SPEI values for classification of drought/wet severity.

Drought/wet severity	SPEI values
Extremely wet	≥2
Severely wet	1.5 to 1.99
Moderately wet	1 to 1.49
Mildly wet	0.5 to 0.99
Normal	−0.49 to 0.49
Mild drought	−0.99 to −0.5
Moderate drought	−1.49 to −1
Severe drought	−1.99 to −1.5
Extreme drought	≤2

1.3.3. The Rainfall Anomaly Index (RAI)

Rainfall Anomaly Index is a valuable tool in evaluating and quantifying variations in rainfall patterns in the context of climate change, where rainfall patterns are becoming more unpredictable and extreme. The Rainfall Anomaly Index is a valuable tool for understanding and quantifying the variations in precipitation patterns [21]. By utilizing the Rainfall Anomaly Index, researchers and meteorologists can determine the severity of drought or excess rainfall in a given region. [22] calculated annual rainfall anomaly index from the precipitation data for 34 years to identify the intensity and frequency of past years in the Mathura district. In today's rapidly changing world, the significance of accurate weather forecasts cannot be overstated. Therefore, the rainfall anomaly index is crucial in assessing the impact of climate change on precipitation patterns and enables policymakers to make informed decisions regarding water resource management, agricultural planning, and disaster preparedness [23]. By utilizing the rainfall anomaly index, researchers and meteorologists gain valuable insights into the deviation of precipitation patterns from the long-term norm. RAI serves as a valuable tool for assessing rainfall patterns, understanding climate variability, informing agricultural practices, managing water resources, and enhancing resilience to climate-related risks. It provides a quantitative measure to evaluate deviations from the norm and contributes to informed decision-making in various sectors. In agriculture, RAI is utilized to evaluate the rainfall conditions during critical periods for planting, crop growth, and harvesting. It helps in determining the timing of irrigation, adjusting planting dates, and managing water resources effectively. RAI is classified as outlined in **Table 3**.

1.3.4. Mann-Kendall Tests

Named after H. Mann and D. R. Kendall, who introduced it independently. The Mann-Kendall (MK) trend test is a non-parametric statistical method used to evaluate whether a time series has a monotonic upward (positive) or downward (negative) trend. In other words, it identifies a trend in a series [17]. The test assesses the correlation between data points' ranks and their corresponding time periods, effectively detecting patterns without making assumptions about the data's underlying distribution.

Table 3. The RAI values for classification of severity of drought and wet.

Rainfall Anomaly Index (RAI)	Classification
>4	Extremely humid
2 to 3.9	Very humid
0 to 1.99	Humid
−1.99 to 0	Dry
−3.99 to −2	Very dry
<−4	Extremely dry

Source: [24].

2. Methodology

2.1. Study Area

The study area is the Marigat region which is located in Baringo County, Kenya. The area experiences a semi-arid climate, which is characterized by unique precipitation and temperature trends. Its latitude which is close to the equator, contributes to its warm climate. In most cases, the area experiences high temperatures which range between 280C and 350C from December to March which are considered the hottest months in the region [13]. Over time, the region has experienced a noticeable upward trend in average temperature rise due to an increase in the global climate. Most of the rising temperatures occurred during the dry seasons. This high temperature has resulted in prolonged heat spells, thereby affecting sorghum production in the area [13]. Similarly, precipitation has exhibited a bimodal distribution trend over the past. The area receives two rainy seasons in a year, with long rains occurring between March and May, while short rains occur between October and December. However, historical data indicates unpredictability and variability in these rain patterns. The average annual precipitation in the area is approximately 500 - 700 mm; however, variations are experienced in different parts of the area [13]. Traditional rainfall patterns have changed in recent years, with an irregular onset and cessation of rain. In addition, the area tends to experience prolonged dry spells, coupled with intermittent heavy rainfall. These variations in precipitation levels adversely affect sorghum cultivation in the region.

2.2. Climatic Data

The climatic data were obtained from Perkerra Irrigation Scheme, Kenya Agricultural and Livestock Research Organization (KALRO) Marigat station and supplemented with the data from Kenya Meteorological Department and NASA power. The surface temperature (minimum and maximum) and precipitation for the period 1990 to 2022 were used in the analysis. The datasets provided daily, monthly, seasonal, and annual for precipitation and monthly average for temperature. AMJJ (April-July) values estimate trends in long rainy seasons, while SOND (September-December) values are useful for short rainy seasons.

Analysis was done from the climatic data to determine rainfall variability, duration, intensity, frequency, amount and trends available. This should also help to estimate planting date trends ever since. To help with this, drought indices were used to determine the variability.

2.3. SPI, SPEI, RAI, Mann Kendall, and Scope of Index Analysis

To validate the accuracy of the climate variability, it was important to compare the results obtained amongst the standardized anomaly indices such as the Standardized Precipitation Index, Standardized Precipitation-Evapotranspiration Index, and Rainfall Anomaly Index. To accomplish this study, three drought indices SPI, SPEI and RAI were calculated for historical climate data. The indices are discussed below.

2.3.1. Standardized Precipitation Index (SPI)

The Gamma distribution is the best in calculating SPI amongst the most used probability functions (Gumbel, Gamma, and Weibull). This is due to its relatively flexible shape parameter [25]. The cumulative precipitation time series at different timescales is necessary before calculating the probability distribution. It is calculated as outlined.

$$X_{i,j}^{k} = \sum_{l=31-k+j}^{30} P_{i-1,l} + \sum_{l=1}^{j} P_{i,j}, \text{ if } j < k \text{ and } X_{i,j}^{k} = \sum_{l=j-k+1}^{j} P_{i,l}, \text{ if } j \geq k \quad (1)$$

where;

$X_{i,j}^{k}$: The cumulative precipitation amounts on a given day j in year i at timescale k (days)

$P_{i,j}$: The daily precipitation amounts on day j in year i.

The gamma probability distribution function to calculate the probability distribution of the accumulated precipitation time series is then introduced. The probability density function is given as;

$$f(x) = \frac{1}{\beta^{\gamma}\Gamma(\gamma)} x^{\gamma-1} e^{-\frac{x}{\beta}}, \quad x > 0, \quad (2)$$

where; $\Gamma(\gamma) = \int_0^{\infty} x^{\gamma-1} e^{-x} dx$

The scale and shape parameters are calculated by the maximum likelihood estimation method as follows;

$$\hat{\gamma} = \frac{1 + \sqrt{1 + \frac{4}{3}A}}{4A}; \quad \hat{\beta} = \frac{\bar{x}}{\hat{\gamma}} \quad (3)$$

$$\text{and} \quad A = \lg \bar{x} - \frac{1}{n}\sum_{i=1}^{n} \lg x_i \quad (4)$$

where;

$\hat{\gamma} > 0$: Shape parameter

$\hat{\beta} > 0$: Scale parameter

x and x_i: The cumulative precipitation time series at a certain timescale *n*: The number of precipitation time series samples

$\overline{x}$: The average of the precipitation time series samples

The probability that the random variable *x* is less than the precipitation x_0 on a certain time scale is given by the following equation;

$$P(x < x_0) = \int_0^{x_0} f(x)\mathrm{d}x \tag{5}$$

Since the domain of the gamma function does not include the case of $x = 0$ and the actual precipitation amount maybe 0, the piecewise probability distribution is then given as;

$$P(x) = \begin{cases} P_0 + (1 - P_0)F(x) & x > 0 \\ \dfrac{m+1}{2(n+1)} & x = 0 \end{cases} \tag{6}$$

where;

P_0 : The historical ratio of periods with zero precipitation

$F(x)$: The probability distribution for samples with detectable accumulated precipitation.

n: The number of samples

m: The number of samples where total precipitation equals zero,

Then the gamma probability distribution is normalized using the following function;

$$P(x < x_0) = \frac{1}{\sqrt{2\pi}} \int_0^{x_0} \mathrm{e}^{-\frac{z^2}{2}} \mathrm{d}x \tag{7}$$

SPI is then determined by;

$$\mathrm{SPI} = z = S\frac{c_0 + W - c_1 W - c_2 W^2}{1 + d_1 W + d_2 W^2 + d_3 W^3} \tag{8}$$

where; $W = \sqrt{\ln\frac{1}{P^2}} \begin{cases} P = 1 - F(x), S = -1 & F(x) \le 0.5 \\ P = 1 - P, S = 1 & F(x) > 0.5 \end{cases}$

Constants; $c_0 = 2.515517,\ c_1 = 0.802853,\ c_2 = 0.010328,$
$d_1 = 1.432788,\ d_2 = 0.189269,\ d_3 = 0.001308$

2.3.2. The Standardized Precipitation Evapotranspiration Index (SPEI)

The principle of SPEI uses the degree of the difference between precipitation and evapotranspiration which deviates from the average status to represent the regional drought. This index is used to represent regional drought conditions, taking into account factors such as climate variability and temperature.

$$D_n^k = \sum_{i=0}^{k-1}\left(P_{n-i} - PET_{n-i}\right),\ n \ge k, \tag{9}$$

where;

D: The difference between precipitation and potential evapotranspiration

P: The monthly precipitation

PET: The monthly potential evapotranspiration

K: Time scale

n: Calculation frequency

SPEI index is calculated based on log-logistic distribution where its probability density function is used to fit the sequence.

$$f(x)=\frac{\beta}{\alpha}\left(\frac{x-\gamma}{\alpha}\right)^{\beta-1}\left[1+\left(\frac{x-\gamma}{\alpha}\right)^{\beta}\right]^{-2} \tag{10}$$

where γ, β, and α are origin, shape and scale parameters

$$\beta=\frac{2\omega_1-\omega_0}{6\omega_1-\omega_0-6\omega_2}, \tag{11}$$

$$\alpha=\frac{(\omega_0-2\omega_1)\beta}{\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right)}, \tag{12}$$

$$\gamma=\omega_0-\alpha\Gamma\left(1+\frac{1}{\beta}\right)\Gamma\left(1-\frac{1}{\beta}\right) \tag{13}$$

where;

$\Gamma\left(1+\frac{1}{\beta}\right)$: Gamma function of $\left(1+\frac{1}{\beta}\right)$

ω_s: The probability-weighted moments (PWMs) of order s

S = 0, 1, 2 formula as shown,

$$\omega_s=\frac{1}{n}\sum_{i=1}^{n}\left(1-\frac{j-0.35}{n}\right)^{s}D_i \tag{14}$$

n: The number of data points sand

j: The range of observations in increasing order

The probability distribution function of the log-logistic distribution for the *D* series is expressed using the following equation.

$$F(x)=\left[1+\left(\frac{\alpha}{x-\gamma}\right)^{\beta}\right]^{-1} \tag{15}$$

The SPEI value can then be determined as the standardized value of *F*(*x*) with the following formula

$$\text{SPEI}=\frac{c_0+c_1W+c_2W^2}{1+d_1W+d_2W^2+d_3W^3}, \tag{16}$$

$$W=\sqrt{-2\ln(P)}\ \text{ for } P\le 0.5, \tag{17}$$

where;

P: The probability of exceeding a determined *D* value and $P = 1 - F(x)$; when $P > 0.5$, $P = 1 - P$

Constants; $c_0=2.515517,\ c_1=0.802853,\ c_2=0.010328,$

$d_1=1.432788,\ d_2=0.189269,\ d_3=0.001308$

2.3.3. Rainfall Anomaly Index (RAI)

Annual Rainfall Anomaly Index (RAI) can help in analysing the frequency and intensity of the dry and rainy years. RAI, which was developed by [26], constitutes the following equations:

$$\text{RAI} = -3\left[\frac{N-\bar{N}}{\bar{M}-\bar{N}}\right], \text{ For positive anomalies} \tag{18}$$

$$\text{RAI} = -3\left[\frac{N-\bar{N}}{\bar{X}-\bar{N}}\right], \text{ For negative anomalies} \tag{19}$$

where;

N: Current monthly/yearly/seasonal rainfall (mm),

$\bar{N}$: Average monthly/yearly/seasonal rainfall (mm) of the historical series

$\bar{M}$: Average of the ten highest monthly/yearly/seasonal precipitations (mm) of the historical series

$\bar{X}$: Average of the ten lowest monthly/yearly/seasonal precipitations (mm) of the historical series; and positive anomalies have their values above average and negative anomalies have their values below average

2.3.4. The Mann-Kendall (MK) Trend Test

The Mann-Kendall Test is used to determine whether a time series has a monotonic upward or downward trend. This method was applied to determine whether there was a trend in temperature. The null hypothesis for this test is that there is no trend, and the alternative hypothesis is that there is a trend in the two-sided test or that there is an upward trend (or downward trend) in the one-sided test. For the time series $x_1, \cdots, x_n$. The non-parametric Mann-Kendall test was used to detect trends of variables in meteorology. Statistic S can be obtained by equation below.

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\left(x_j - x_i\right) \tag{20}$$

where;

x_i and x_j: The values of sequence *i*, *j*

n: The length of the time series

$$\text{and; } sgn\left(x_j - x_i\right) = \begin{cases} 1, & \text{if } \left(x_j - x_i\right) > 0 \\ 0, & \text{if } \left(x_j - x_i\right) = 0 \\ -1, & \text{if } \left(x_j - x_i\right) < 0 \end{cases}$$

where *n* is the length of the sample, x_i and x_j are from $i = 1, 2, \cdots, n-1$ and $j = i+1, \cdots, n$. The mean of *S* is 0. The variance of statistics *S* is given as:

$$var = \frac{1}{18}\left[n(n-1)(2n+5) - \sum_{i=1}^{m} T_i i(i-1)(2i+5)\right] \tag{21}$$

where;

T_i : The number of data in the tied group

M: The number of groups of tied ranks

The standardized test statistic *Z* is computed by;

$$Z = \begin{cases} \frac{S-1}{\sqrt{var}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{var}}, & \text{if } S < 0 \end{cases} \quad (22)$$

The three alternative hypotheses are that there is a negative, non-null, or positive trend. If $Z > 0$, it indicates an increasing trend, and vice versa. Besides, the magnitude of a time series trend was evaluated by a non-parametric procedure developed by Sen as shown below;

$$\beta = Median\left(\frac{x_j - x_i}{j-i}\right), \quad j > i \quad (23)$$

where β is Sen's slope estimate. $\beta > 0$ indicates an upward trend in a time series. Otherwise, the data series presents a downward trend during the time period.

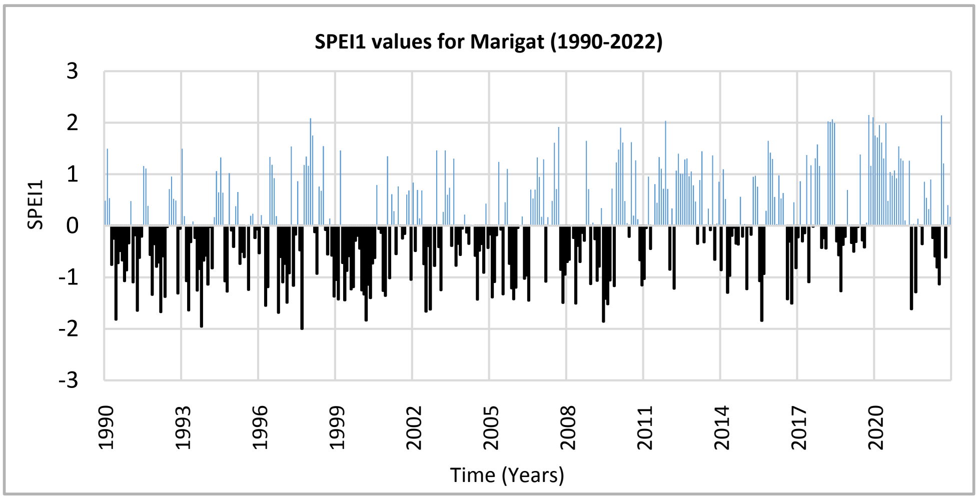
3. Results

The variability of annual and seasonal precipitation was assessed using anomaly indices. The Mann-Kendall trend test approach was applied to examine the trends in temperature in the region over the past 32 years. The results indicated that the short rainy season was more erratic and unstable compared to the long rainy season, which is the main growing season. The movement of the SPI, SPEI, and RAI index graphs indicates above or below-average rainfall, with upward movements corresponding to above-average rainfall and downward movements corresponding to below-average rainfall.

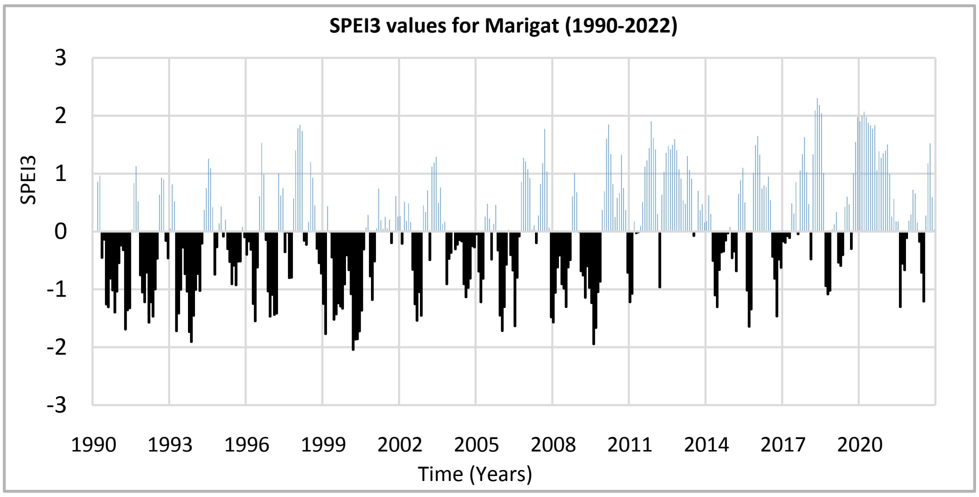
The year 1997 was the driest with SPEI value of −2.0025. The years 1993, 2009, 2015, 2000, 1990, 1996, 1992, 2002, 1991, 1993, 2002, 2021, 1996, 2009, 2016, and 2008 were very dry (SPEI was between -1.5 to -1.99) as shown in **Figure 1** and **Figure 2**. On the other hand, the years 1998, 2011, 2018, 2019, 2020, and 2022 were very wet with SPEI values of more than 2. This information indicates the changing weather patterns over the years.

Figures 3(a)-(c) show the Rainfall Anomaly Index (RAI) for each year from 1990 to 2022. Low RAI numbers were seen in 1990, 1991, 1992, 19931995, 1996, 1999, 2000, 2002, 2004, 2005, 2006, 2008, 2009 and 2014. These values indicate that there was less rain than usual during these times. On the other hand, high RAI numbers in 2020, 2019, 2018, 2017, 2015, 2013, 2012, 2011, 2003, and 1997 indicating wet years. 2020 indicated more rain than usual. It shows a very high RAI of 8.25, which suggests that there was extra rainfall during that time. The year 2000 was the driest year with an anomaly index of −4.34847.

The analysis of the rainfall anomaly index (RAI) has revealed a trend indicating that the Short Rainy Season (SOND) has been the most variable period for rainfall across the years. The highest positive anomaly recorded for SOND was 6.32, which occurred in 2019. In contrast, the Long Rainy Season (AMJJ) recorded the highest positive anomaly index of 8.18, while the highest negative



(a)



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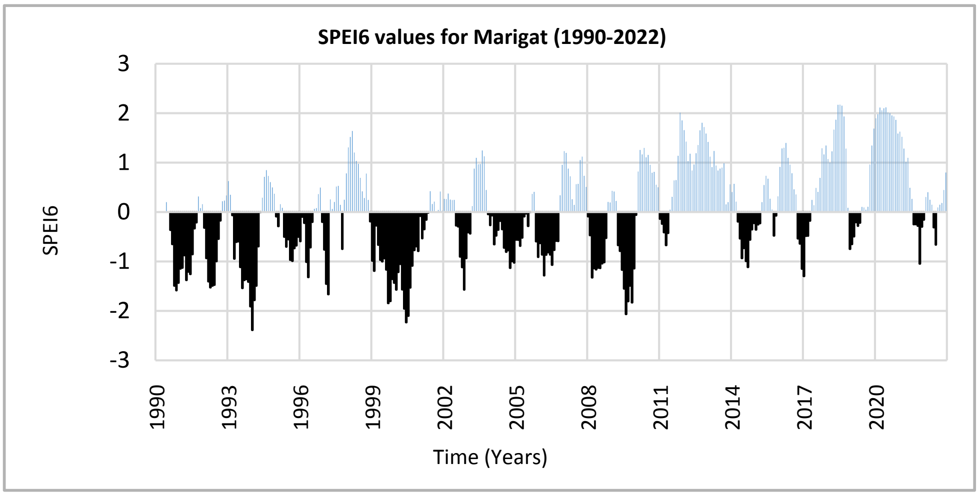
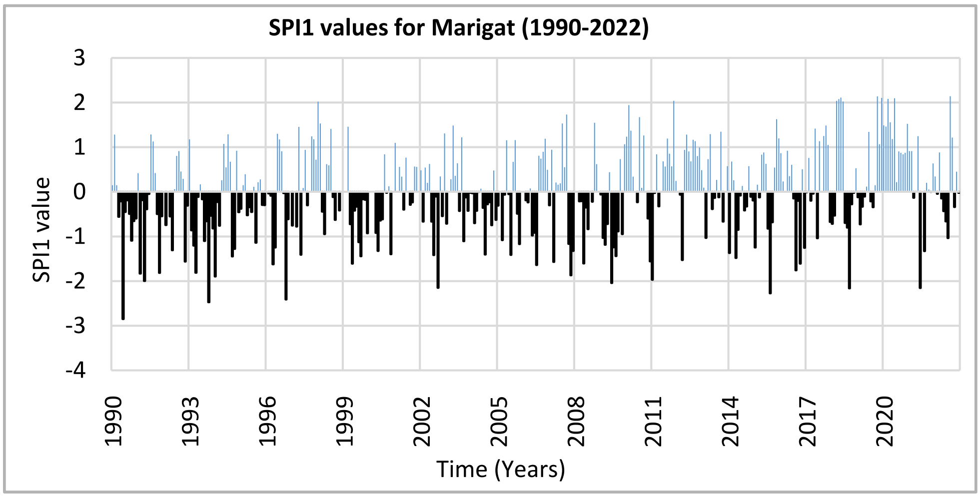


(c)

Figure 1. (a) SPEI1 value of Marigat for the period 1990-2022. (b) SPEI3 value of Marigat for the period 1990-2022. (c) SPEI6 value of Marigat for the period 1990-2022.



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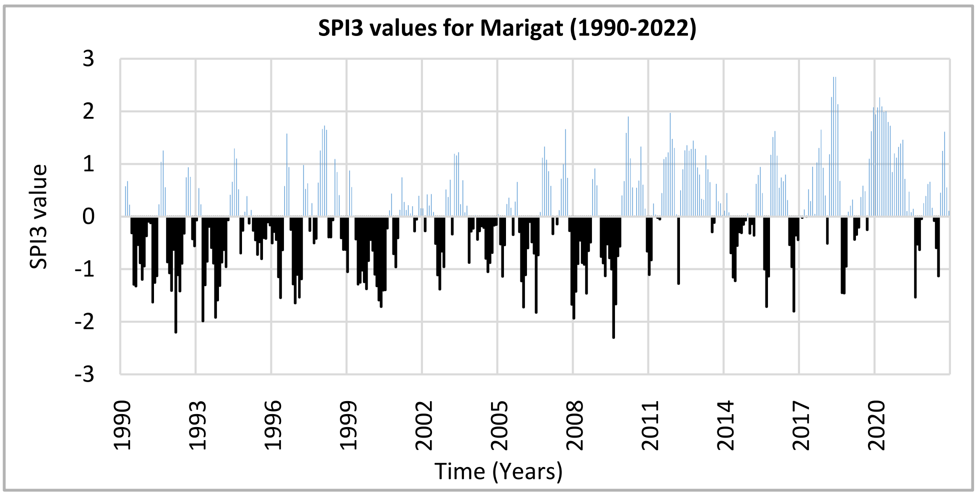

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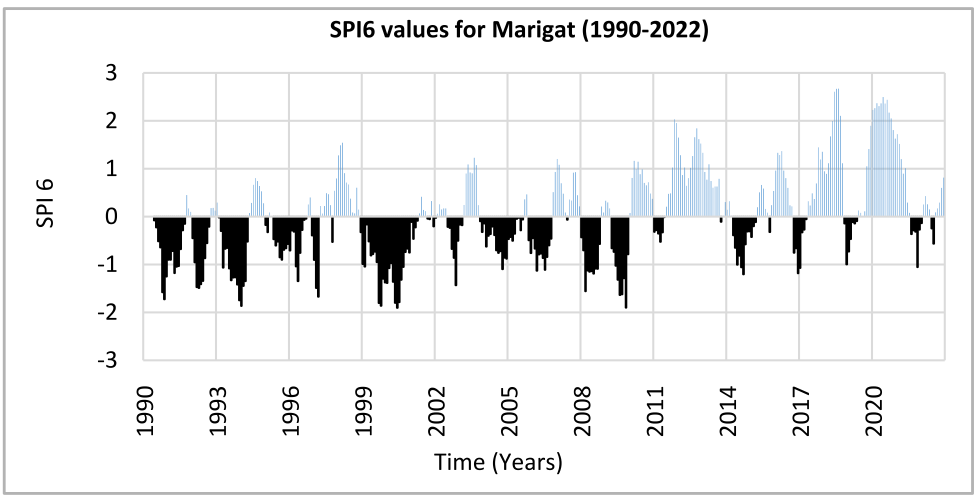

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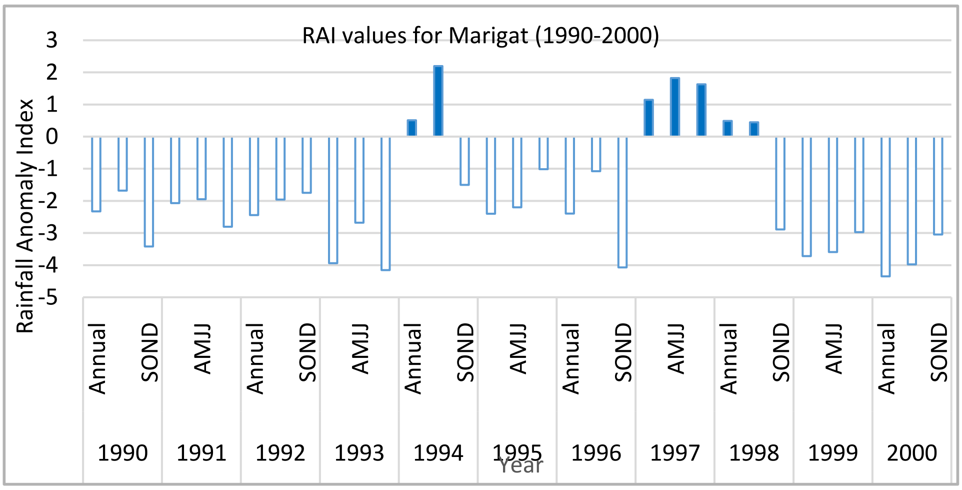
Figure 2. (a) SPI1value of Marigat for the period 1990-2022. (b) SPI3 value of Marigat for the period 1990-2022. (c) SPI6 value of Marigat for the period 1990-2022.



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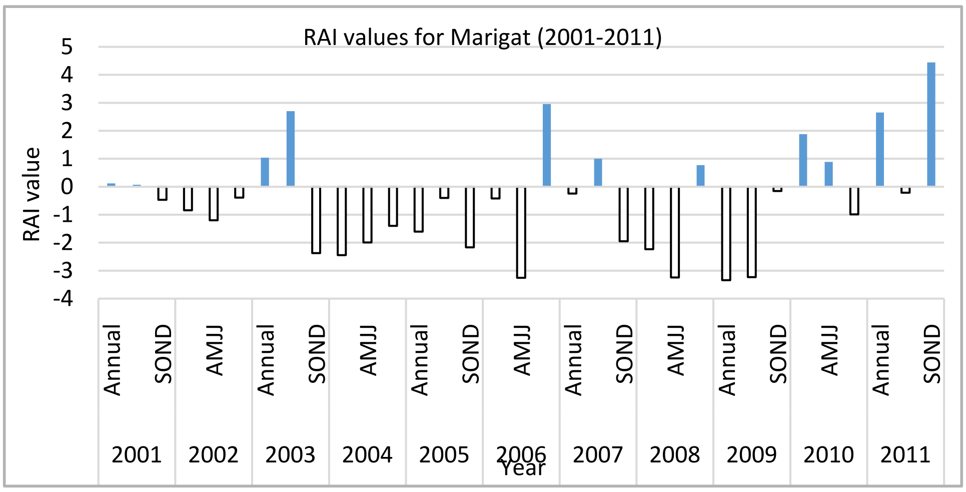

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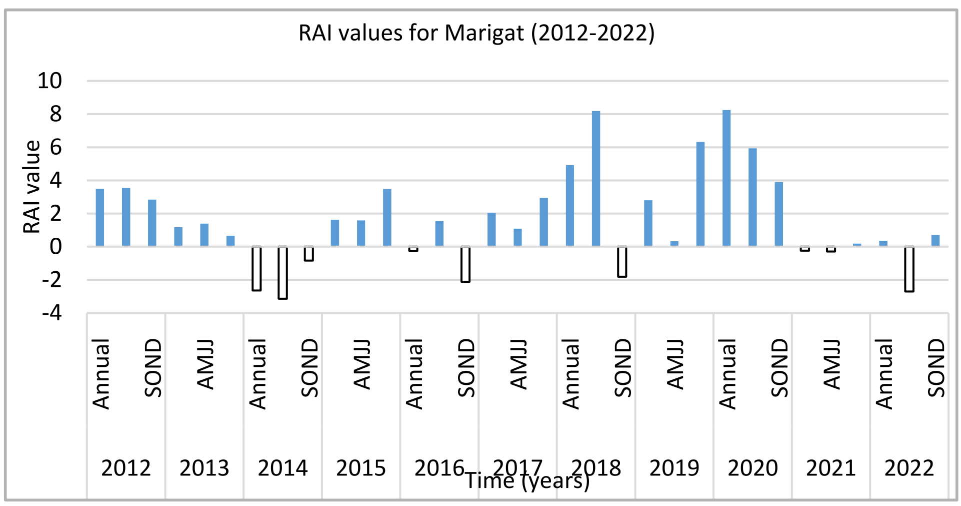

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Figure 3. (a) RAI value for Marigat for the period 1990-2000. (b) RAI value for Marigat for the period 2001-2011. (c) RAI value for Marigat for the period 2012-2022.

anomaly index of −3.97 was recorded in 2000. It is noteworthy that SOND received more rainfall than the AMJJ season in that year (Table 4).

The Mann-Kendall (MK) Test

MK trend test on average monthly rainfall, SOND AMJJ and annual shows that there exists a positive trend in precipitation. Analysis in SOND confirms a positive trend to AMJJ months which shows no trend (Table 5).

Table 4. Classification of years with respect to the severity of the drought using RAI

Years	Rainfall Anomaly Index (RAI)	Classification
2018, 2020	>4	Extremely humid
2017, 2011, 2019, 2012	2 to 3.99	Very humid
2001, 2022, 1998, 1994, 2003, 1997, 2013, 2015, 2010	0 to 1.99	Humid
2005, 2002, 2006, 2016, 2007, 2021	−1.99 to 0	Dry
1993, 1999, 2009, 2014, 1992, 2004, 1995, 1996, 1990, 2008, 1991	−3.99 to −2	Very dry
2000	<−4	Extremely dry

Table 5. The Mann-Kendall (MK) trend and Sen's slope show the existence of trends.

Month	z	MK Tau	Sen's Slope	P-value	Trend exist
January	1.0281	0.1294953	0.12937	0.3039	NS
February	1.8693	0.2338646	0.34961	0.06158	NS
March	1.7976	0.221801	0.80132	0.07225	NS
April	2.0917	0.2575758	2.76090	0.03646	**Exist**
May	2.3706	0.2916667	2.04809	0.01776	**Exist**
June	0.79022	0.0984848	0.58784	0.4294	NS
July	−1.0381	−0.128787	−0.84407	0.2992	NS
August	−0.72824	−0.090909	−0.34633	0.4665	NS
Sept	1.8438	0.2272727	0.99635	0.06521	NS
October	1.9368	0.2386364	1.11605	0.05277	NS
November	2.6186	0.3219697	1.95714	0.00883	**Exist**
December	2.3321	0.2901358	1.26809	0.0197	**Exist**
AMJJ	1.7199	0.2121212	4.009	0.08545	NS
SOND	3.8581	0.4734848	5.260417	0.0001143	**Exist**
ANNUAL	3.2383	0.3977273	12.56833	0.001202	**Exist**

NOTE: NS - Not Significant, 5% level of significance.

4. Discussion

Time series for monthly, seasonal, and annual patterns for precipitation and maximum and minimum temperatures were analysed for the specified area of Marigat in Baringo County. Both the SPEI and SPI values also fluctuated, and the trend was unpredictable. There was no clear pattern in the SPEI and SPI values. However, in some years, the values for the SPEI and SPI were high, while in other years, the values were low. Both the SPEI and SPI values increased slightly. The trend seems to be an upward movement for some years; however, it is still not on the upward trajectory path, as expected. The highest values for both SPEI and SPI were recorded in 2020, indicating that there was a lot of rain in that year as compared to other years. Similarly, earlier years, for example, 1990, 1991, and 1992, tend to have low values for both SPEI and SPI, meaning that rainfall was low in those years. As seen in **Figures 1(a)-(c)**, the AMJJ months have relatively higher SPEI and SPI values than other months, such as SOND. It is clear that during these months, the Marigat area receives relatively high rainfall which conforms to the ideology of the high/long rainfall season. Therefore, farmers should plant their seeds in these months since they will be sure of having some harvest compared to other months, such as SOND months.

During the months of short rain (September, October, November, and December), high variations were noted. However, for the long rainy months (*i.e.* April, May, June, and July), with minimal variations. Most of the RAI values between 1990 and 2000 were negative, meaning that rainfall was inadequate and sorghum could not do well. The highest RAI value was recorded in 2020 (8.25), and the lowest value was recorded in the year 2000 (4.35). Based on these values, this trend was unpredictable for most years. It means, therefore, that the farmers need to look for alternative sources of water for purposes of having consistency in the yield of sorghum (Rowell *et al.*, 2015). However, over-reliance on rain-fed farming might not be profitable because of the unpredictable nature of rainfall in the region (Grossi *et al.*, 2015). MK trend test on average monthly rainfall, SOND, AMJJ and annual also confirmed the existence of a positive trend in precipitation. The rainfall amount tends to shift towards short rains.

When studied over a period of time, it is evident that historical records for both rainfall and temperature reveal a complicated interplay of climatic elements that significantly affect agricultural activities in the area. Trends in temperature in Marigat within a period of 32 years (1990-2022) as studied in this paper, exhibited a discernible change in pattern. For example, the daily average temperature has increased over the past decade [4]. This gradual increase in temperature has raised concerns among experts in agriculture as well as local farmers. With respect to the historical data analysis, it was evident that the rise in temperature was not uniform across the different seasons. Some seasons have experienced a moderate increase, while other seasons have experienced a spike, which has greatly affected sorghum production [4]. In addition, the constant rise in temperature has greatly contributed to extended hot spells, which in turn has intensified the challenges faced by sorghum farmers in the region. During the day, the region experiences higher temperatures than those at night. Temperatures soared high more so during dry seasons, thereby causing water stress in crops. The drop in temperature at night can slow the growth and development of sorghum and other crops. Sorghum's ability to withstand various abiotic stresses such as heat and drought, as well as extensive periods of water logging, reinforces it as a key climate change adaptation choice crop in Marigat, Baringo County [14]. However, there is a lack of knowledge about the specific response of sorghum to future climate change in this region [27]. The altering weather patterns in Marigat, Baringo County, such as heightened precipitation and flooding, as well as elevated temperatures, present considerable threats to the cultivation of sorghum [28].

4.1. Trends in Temperature

The historical records of temperature in Marigat have tended to reveal a rising trend over the past decades. As noted by [5], there has been a consistent increase in daily average temperatures during periods of short rain. At an elevation of 1024.24 metres, the region has both wet and dry climates. March experiences high temperatures compared to other months. However, the increase in temperature in the region is not uniform because dry seasons are much hotter than wet seasons. Moreover, there was a notable fluctuation in the temperature during the day and night. Temperatures experienced during the day are extremely high compared to those experienced at night. A drop in temperature at night has an adverse effect on sorghum growth. These temperature changes include an overall increase in temperatures, particularly during the growing season. These temperature increases can have various effects on sorghum production. Higher temperatures during the growing season can accelerate the growth and development of sorghum plants, leading to shorter maturation periods, and increased water stress on the plants, as higher temperatures increase evaporation rates and moisture loss from the soil [29]. (**Figure 4**)

4.2. Trends in Precipitation

The data indicates a possible increasing trend in overall annual rainfall, with more frequent and intense dry spells and droughts. These changes in precipitation patterns can have significant implications for sorghum production, as the crop relies heavily on rainfed farming [30]. Marigat received below-average rainfall in multiple seasons. The rainfall ranged from below average, average to above average over the period of study. **Figure 5(b)** shows Annual, AMJJ and SOND rainfall with an increasing trend. SOND increases at a high rate while AMJJ increases at a slow rate. Rainfall received in AMJJ accounts for nearly 60% of the total rainfall. The rainfall received in SOND is little and might not be sufficient to cushion crops from water scarcity. There are significant differences in the rainfall distribution pattern. July and August have above average rainfall though agricultural activities have reduced by then. Rainfall assumes an increasing trend from the onset up to the month of November when the peak is reached. (**Figure 5**)

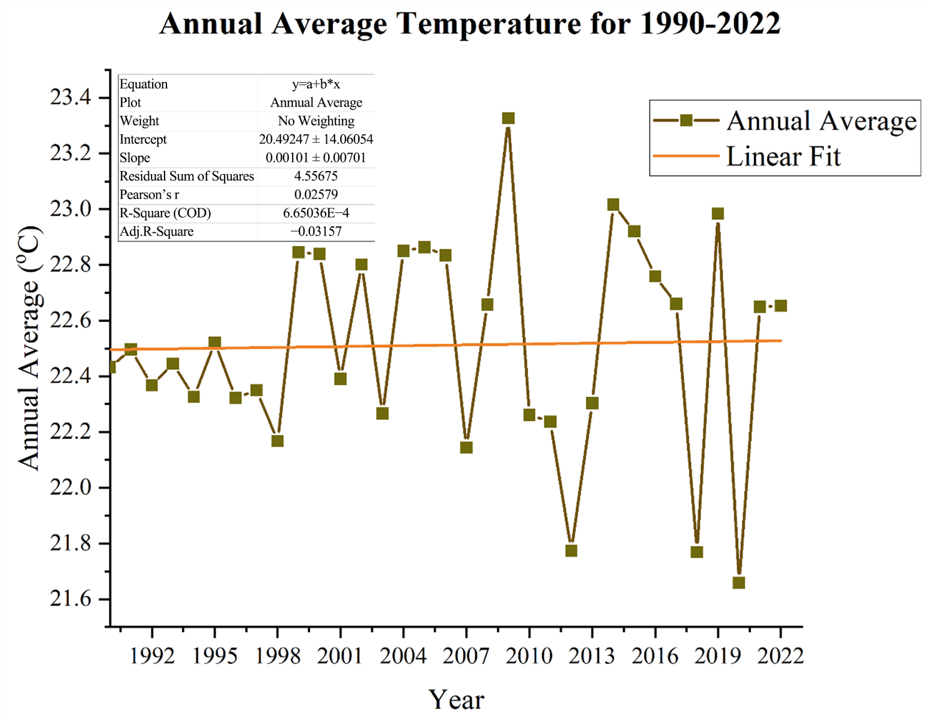
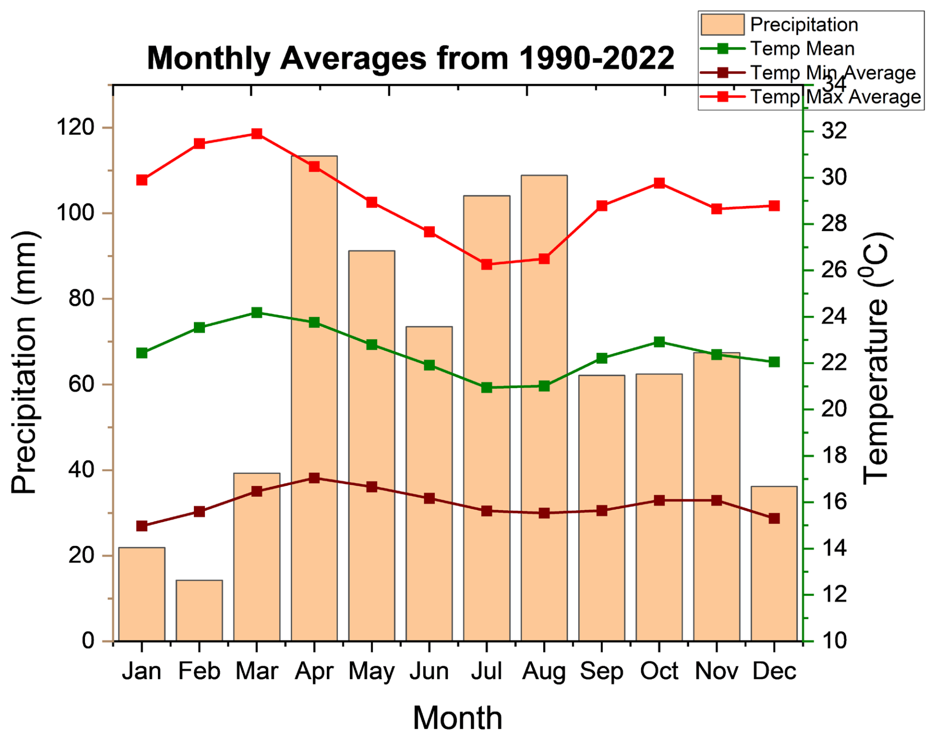


Figure 4. Annual average temperature of Marigat for 1990-2022.



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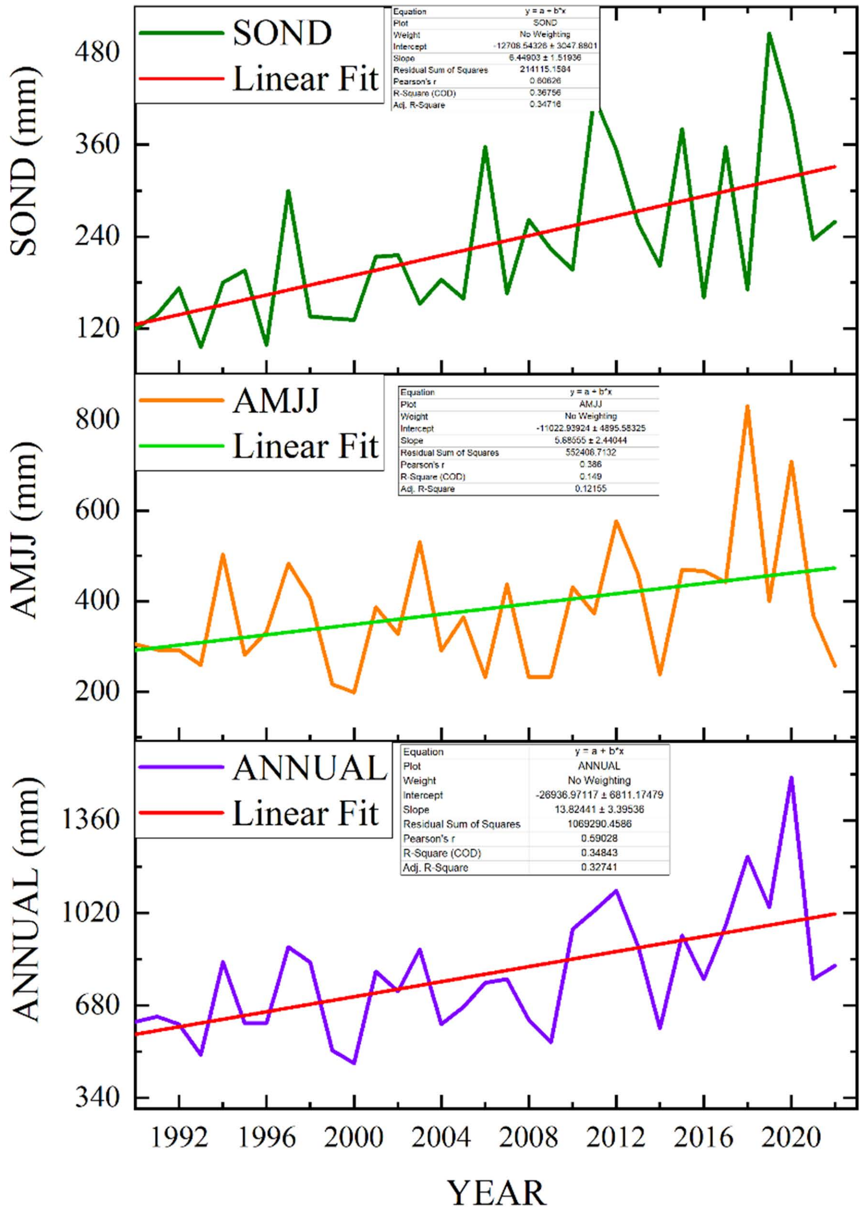

(b)

Figure 5. (a) Monthly averages, of Rainfall and Temperature (minimum, maximum, and average) for Marigat for 1990-2022. (b) Annual and seasonal (SOND, and AMJJ) rainfall from 1990-2022.

5. Conclusion and Recommendation

Historical climatic data analysis of the Marigat area revealed intricate trends in both precipitation and temperature. Based on data gathered from 1990 to 2022, the trend seems unpredictable because the graph of fluctuations is not clear. For example, in 2020, there was a high value for SPEI, RAI, and SPI as compared to other years. This means that the amount of rainfall in that year was relatively high, which is why these values escalated. In the shortest rainy season (SOND months), temperatures were relatively high compared to the long rainy season, that is, AMJJ months. Based on the temperature trends, it is advisable for farmers to plant during the AMJJ months because these months have higher values for SPEI, RAI and SPI. In those months, the threshold of 1 mm to 2.5 mm per day of water required by sorghum is easy to attain. However, for months such as SOND, the attainment of this threshold seems tricky and unpredictable. It is crucial for farmers and stakeholders in Marigat to monitor and adapt to these changing climatic conditions in order to sustain sorghum production and ensure food security in the area.

Rainfall and temperature variability pose challenges to sorghum production in Marigat, Baringo County, including accelerated growth, shorter maturation periods, increased water stress, reduced yield and quality, and higher pest pressure (Pests such as aphids and mites thrive in warmer temperatures, leading to increased infestations and potential crop damage). These trends may result in lower crop yields, decreased productivity, and increased vulnerability to climate change impacts. To address these challenges, prioritizing adaptive measures such as climate-smart agricultural practices, improved water management and irrigation techniques, soil conservation practices, drought-tolerant varieties, and pest management strategies can be effective. Implementing weather monitoring systems and early warning systems can also help farmers anticipate and mitigate the impacts of extreme weather events such as droughts and floods.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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