

Temperature and Rainfall Trends Analysis using Mann-Kendall and Sen's Slope Estimator Test in Marsabit County, Kenya

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Abstract

This paper analysed monthly, seasonal and annual climate data for trends of precipitation, maximum temperature and minimum in Marsabit County. This study used Mann–Kendall test and Theil-Sen's slope estimator to analyze monthly, seasonal and annual temperature and precipitation trends for Marsabit County from 1990 to 2022. The findings revealed a decreasing, but non-significant, trends in the monthly, seasonal and annual precipitation. When the monthly, seasonal and annual data for maximum and minimum temperature was evaluated, the results revealed an upward and statistically significant ($p \leq 0.05$) trend. The findings revealed a statistically significant upward trend in the county's annual and seasonal minimum and maximum temperatures across the study period. An analysis of the sub-county data shows results which are consistent with the overall county for precipitation, maximum temperature and minimum temperature. These results suggest that Marsabit County has been experiencing climate change. There is need to develop climate change adaptation strategies targeted at mitigating risks and increasing resilience to climate shocks.

Keywords: Mann-Kendall, Sen's Slope, Precipitation; Maximum Temperature; Minimum Temperature

1. Introduction

The rate of global warming is higher than it has ever been. Weather patterns are shifting due to rising temperatures, upsetting the natural equilibrium of the environment. The extent and magnitude of climate change impacts are larger than estimated in previous assessments (IPCC, 2023). Climate change is accompanied by impacts that have far reaching effects on biodiversity, landscapes, people and their socio-economic structures. Globally, precipitation has been declining while temperature has been increasing. Africa's climate is projected to become warmer and drier in future and with high possibilities of more intense variabilities that may give rise to droughts, heatwaves, violent storms, cyclones and floods among other extreme climatic events IPCC (2012).

Research of rainfall and temperature trends in several regions in Kenya has been carried out to determine climate change and variability impact on several sectors. An analysis of rainfall and temperature trends in Makuani County (Muia et al., 2024) has shown a declining trend of annual and monthly rainfall as well as increasing trend of annual and monthly rainfall. Gudere et al (2023), who studied the temperature and precipitation trends in Marsabit County, states that the temperature trends are increasing and precipitation trends are declining in the county. Using the Mann-Kendall and Sen's Slope Test, Nyakundi et al (2022) found that the trend of temperature was increasing while precipitation trend was decreasing in Kwale County.

The use of parametric and non-parametric tests has been used in detection of trends of annual and monthly averages of precipitation and temperature (Sonali and Kumar, (2013). The normal distribution is assumed for statistical parametric tests. However, for non-parametric statistical tests the normality assumption is relaxed. Although parametric trend tests are more reliable, they are more prone to outliers and require normally distributed data. The actual distribution of the data has no bearing on the Mann-Kendall test. Because it is based on the ranks of the observations rather than their actual values, it is less vulnerable to outliers (Hamed, 2008).

The frequency and intensity of weather patterns are changing in many parts of Kenya (Yvonne et al. 2020). The decreasing rainfall trends have affected the production assets and traditional coping capabilities that support livelihoods of pastoralists (Dabasso and Okomoli, 2015; Mulinya, 2017; Muhati et al., 2018; Cuni-Sanchez et al., 2019). Research on the temperature and precipitation trends in Marsabit County is a first step in assessing climate change impact of Gabbra farmers who practice nomadic pastoral livestock production primarily, keeping cattle, sheep, goats and camels. This study analyzed monthly, seasonal and annual temperature and precipitation trends in Marsabit County. The results are useful in developing a more effective plan for mitigation and adaptation to climate change.

2. Methodology

2.1. Study area

Marsabit County (Figure 1) has an arid climate, with the exception of few isolated areas around Mt. Marsabit, Mt. Kulal, Hurri Hills, and the Moyale-Sololo escarpment, which are semi-arid grazing grounds. The temperature ranges from 15°C to 26°C, an average of 20.5°C annually. The precipitation pattern is bimodal with the peak being experienced between April to May. Rainfall ranges from 200mm to 1,000mm per year and is affected by altitude and slope direction both which to an extent determine rainfall duration, amount, and reliability. Mt. Marsabit and Mt. Kulal receive 800mm of rain per year, while North Horr receives about 150mm. The Gabbra ethnic groups which mostly practices nomadic pastoralism primarily inhabits Hurri Hills.

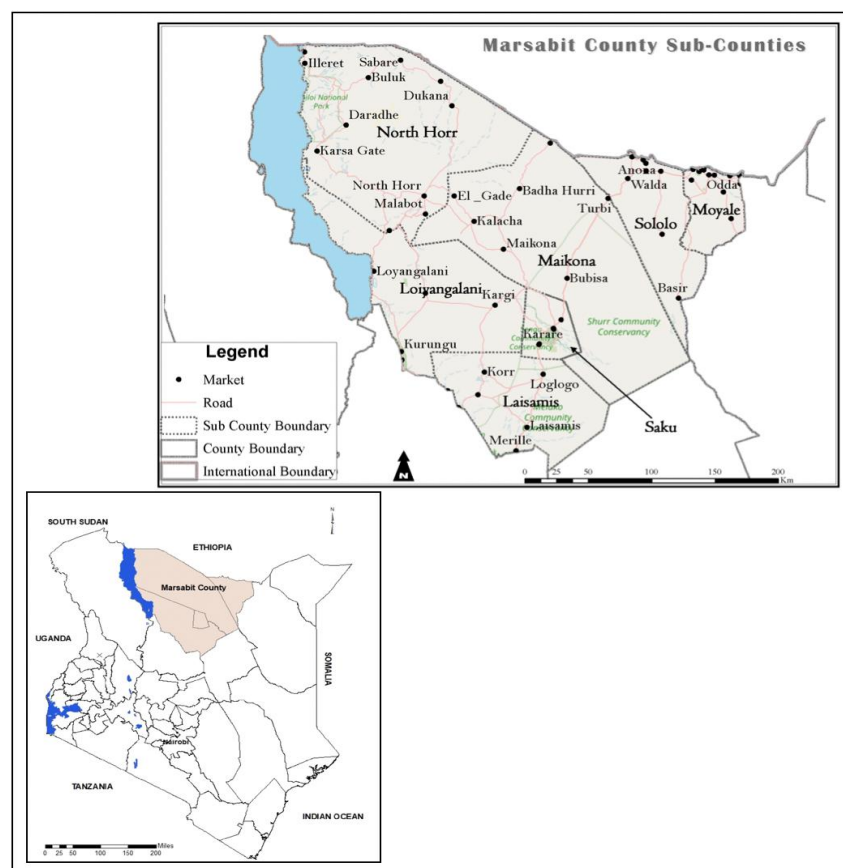


Figure 3.1 shows the study area of Gabbra area in Marsabit County, Kenya

2.2. Data collection

The analysis of trend demands lengthy time-series data in order to reliably detect trends in rainfall and temperature. In this study, secondary data for rainfall and temperature was obtained from the Kenya Meteorological Department for the period 1990-2022.

2.3. Data analysis

The Mann-Kendall (MK) non-parametric trend test (Mann, 1945, Kendall, 1975) was used to detect monotonic trends in temperature and rainfall (identify the presence of a trend), and Sen's estimate (Sen, 1968) was used to assess the magnitude of the trend. The 95% confidence level was used to determine the significant trends for temperature and rainfall data.

2.3.1. Mann-Kendall Test (MK₁)

Mann-Kendall (MK) test is used to determine monotonic upward or downward trend in a time series data. This test does not require the assumption of data normality because it is non-parametric. MK is also less sensitive to sudden breaks, which are instigated by non-homogenous time series. It is based on two hypotheses: the null hypothesis (H₀) which indicates no trend (no change in the series mean) and the alternative hypothesis (H₁) which indicates the presence of a monotonic trend (a rise or decrease in the mean over time).

MK test uses the time series of k data points and considers x_i and x_j as two data subsets where $i = 1, 2, 3, \dots, k-1$ and $j = i + 1, i + 2, i + 3, \dots, k$. The data values are assessed as an ordered time series and every data value is compared to the subsequent data values. When the data value of a subsequent period of time is less than a previously sampled data value, the S statistic is reduced by one. However, if the data value of a subsequent period exceeds that of the previous period, the S statistic is increased by one. The total of all these decrements and increments results in the final value of S (Drapela and Drapelova, 2011). The Mann-Kendall test statistic (S) is thus, calculated as follows:

$$S = \sum_{i=1}^k \sum_{j=i+1}^k \text{sign}(x_j - x_i) \quad (1)$$

Where, k is the total number of data points, x_i and x_j are the data values in time series i and j ($j > i$), and $\text{sign}(x_j - x_i)$ is the sign function. The sign function is calculated as shown below:

$$\text{sign}(x_j - x_i) = \begin{cases} 1, & \text{if } x_j - x_i > 0 \\ 0, & \text{if } x_j - x_i = 0 \\ -1, & \text{if } x_j - x_i < 0 \end{cases} \quad (2)$$

The positive and negative values of S imply upward and downward trends respectively (Silva, et al., 2015). If the time series is sufficiently long (number of data values, $k \geq 10$), the S statistics behave essentially normally, and the test is done using a normal distribution with the mean $E(S)$ and variance $V(S)$ as indicated in equations 3 and 4.

$$E(S) = 0 \quad (3)$$

$$V(S) = \frac{k(k-1)(2k+5) - \sum_{i=1}^y z_i(i-1)(2i+5)}{18} \quad (4)$$

Where k is the number of data points, y is the number of tied groups and z_i is the number of ties to the extent of i . The standard normal test statistic Z_S is computed as:

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{V(S)}}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \frac{S+1}{\sqrt{V(S)}}, & \text{if } S < 0 \end{cases} \quad (5)$$

The negative Z_s values indicate decreasing trends whereas positive Z_s values infer increasing trends. A Z-test statistic offers significance levels (SL) for rejecting the null hypothesis. The confidence level (CL) for rejecting the null hypothesis is specified as:

$$CL = 1 - SL \quad (6)$$

The null hypothesis was rejected when $|Z_s| > 1.96$ by adopting a 5% significance level in this study.

2.3.2 Serial correlation effect

A serially independent data is required for Mann-Kendall test. Since time series data is frequently autocorrelated, the trend detection is usually affected by the presence of serial correlation. The presence of positive autocorrelation may lead to the rejection of a null hypothesis thus leading to type 1 error. On the other hand, Type 2 error might occur when the null hypothesis is not rejected in the presence of a negative autocorrelation (Kumar et al., 2009). When serial correlation is detected in a time series, it should be removed in order to appropriately assess the significance of trends. There are several methods that have been proposed to account for the effect of auto-correlation in natural time series data. In this study, This study ‘pre-whitening’ technique was used to reduce the impact of serial correlation on the MK test.

2.3.3 Mann-Kendall Trend Test with Trend-Free Pre-whitening (MK₂)

Pre-whitening is a technique that is employed on autocorrelated series to convert it into an uncorrelated one (“white noise” hence the term whitening) before applying a trend test (von Storch, 1995, Yue et al., 2002, Hamed, 2009). This study used the Trend-Free Pre-whitening procedure whereby lag-1 serial correlation components were eliminated from the series before the MK test. The lag-one autocorrelation coefficient (r_1) was computed using the following equation:

$$r_1 = \frac{\frac{1}{k-1} \sum_{i=1}^{k-1} (x_i - \bar{x})(x_{i+1} - \bar{x})}{\frac{1}{k} \sum_{i=1}^k (x_i - \bar{x})^2} \quad (7)$$

Where x_i represents a value of an observation in a time series, $\bar{x}$ denotes the mean of the time series data sample, and k symbolizes the sample size. The autocorrelation coefficient values were tested using the following equation:

$$r_1 = \frac{-1 \pm 1.96\sqrt{(k-2)}}{k-1} \quad (8)$$

When r_1 was between the upper and lower boundaries of the confidence interval, the time series data were deemed to be serially correlated. As a result, the trend-free pre-

whitening technique, which is a modified MK test, was applied. The equation 9 was used to eliminate the trend and obtain a detrended time series data:

$$x'_i = x_i - (\beta * i) \quad (9)$$

Where:

$$\beta = \text{median} \left| \frac{x_j - x_i}{j - i} \right| \text{ for all } i > j \quad (10)$$

The lag-1 autocorrelations for detrended time series, which are given by x'_i , were calculated using equation 7. In order to find a residual series, equation 11 was used to eliminate the lag-1 autoregressive component (AR(1)) from the detrended series.

$$y'_i = x'_i - r_1 * x'_{i-1} \quad (11)$$

$$y_i = y'_i + (\beta * i) \quad (12)$$

2.3.4 Sen's slope estimator

Mann-Kendall test is used to detect the presence of a trend while Sen's slope estimator is employed to evaluate its magnitude. Sen's slope test assumes a linear trend and characterizes the quantification of temporal change. This test is preferred over linear regression in hydro-meteorological investigations since its robustness against the effect of outliers (Zhang *et al.*, 2005). Sen's slope equation for trend slope estimate (Q) in a sample of M pairs of data is as follows:

$$Q_i = \frac{x_m - x_n}{m - n} \text{ for } i = 1, 2, 3 \dots Z \quad (13)$$

Where x_m and x_n represent data values at times m and n ($m > n$) respectively, and Z denotes the total number of slope observations. Sen's estimated slope is the median of the Z values associated with Q_i . Based on the slopes value of Z, the median of all slopes is ranked from lowest to the highest Q_i as follows:

$$Q = \begin{cases} Q \frac{Z+1}{2} \text{ if } Z \text{ is odd} \\ \frac{1}{2} \left(Q \frac{Z}{2} + Q \frac{Z+1}{2} \right) \text{ if } Z \text{ is even} \end{cases} \quad (14)$$

Where:

$$Z = \frac{k(k-1)}{2} \quad (15)$$

3. Result and Discussion

The temperature and rainfall data was first evaluated for serial correlation using lag-1 autocorrelation at the 5% significance level to ensure that the data was random. In order to offset the effect of serial correlation, the study used the pre-whitening method.

3.1 Trend Analysis of Rainfall in Marsabit County from 1990 to 2022

The study used Mann–Kendall test and Theil-Sen’s slope estimator to analyse the monthly, annual, and seasonal rainfall trends in Marsabit County between 1990 and 2022. Table 1 provides analysis of the monthly mean data on precipitation in Marsabit County. The December and January precipitation trends are negative while the months of February to November have positive trends. However, the MK test did not reveal any statistically significant trend ($p \leq 0.05$) for the mean monthly data. However, the results revealed statistically significant ($p \leq 0.05$) and positive trend for Loiyangalani in April, Marsabit North in August, Marsabit South in September, and Marsabit Central in October in the study period. Figure 1 confirms MK results through decomposition of additive time series for precipitation in Marsabit County from 1990 to 2022. This includes observed, trend, seasonal and random graphs. Table 1: Trend Analysis of Monthly Mean Precipitation in Marsabit County from 1990 to 2022

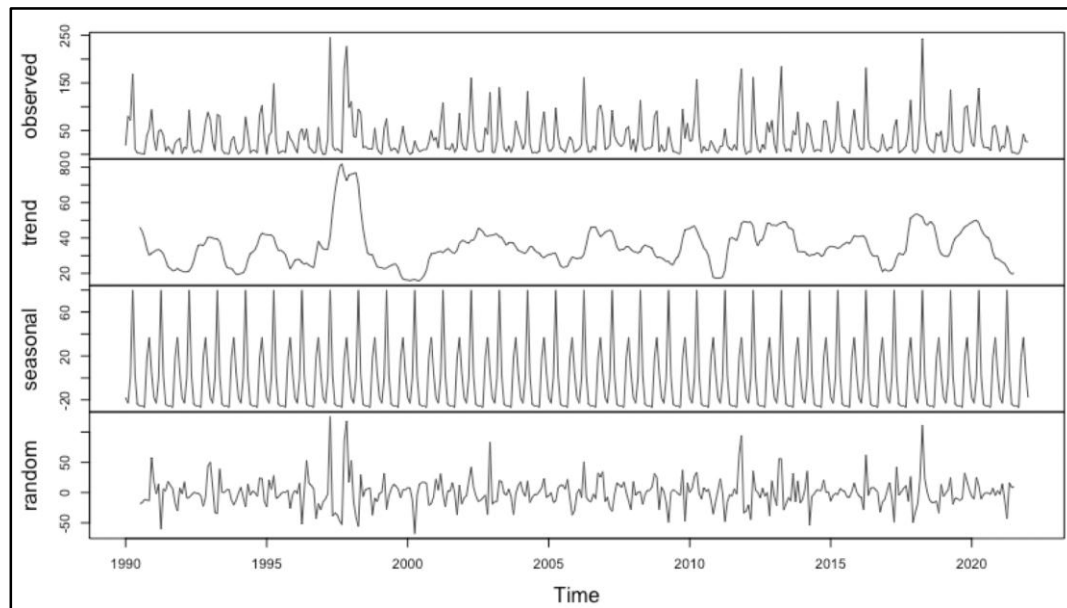
A R E A		J A N	F E B	M A R	A P R	M A Y	J U N	J U L	A U G	S E P	O C T	N O V	D E C
County	ACF	-0.278	-0.128	-0.048	-0.308	-0.096	-0.241	-0.126	0.039	0.101	-0.193	-0.325	-0.242
	Zs	-0.139	0.666	0.047	0.945	0.480	1.348	0.000	0.170	1.7199*	0.945	0.542	-0.449
	Qmed	-0.048	0.123	0.039	0.781	0.178	0.133	0.001	0.014	0.147	0.562	0.225	-0.331
Moyale	ACF	-0.168	-0.128	0.030	-0.281	0.039	-0.118	-0.016	-0.211	0.107	-0.314	-0.221	-0.129
	Zs	-0.697	0.418	0.573	0.449	-0.480	-0.604	-1.829*	0.573	0.232	0.759	0.139	-1.224
	Qmed	-0.062	0.088	0.198	0.521	-0.067	-0.046	-0.052	0.008	0.016	0.735	0.093	-0.406
Loiyangalani	ACF	-0.318	-0.206	-0.244	-0.115	0.170	-0.082	0.067	-0.201	0.113	0.205	0.026	-0.287
	Zs	0.201	-0.078	0.852	2.247**	0.139	1.596	1.224	0.573	1.813*	0.294	-0.666	1.193
	Qmed	0.0	-	0.27	1.	0.0	0.5	0.3	0.1	0.5	0.1	-	0.2

		41	0.0 12	4	89 4	54	26	06	30	38	27	0.1 43	57
Marsabit South	ACF	- 0.2 57	- 0.0 54	- 0.07 4	- 0. 23 3	- 0.0 12	- 0.2 44	- 0.1 35	0.2 22	0.1 34	- 0.0 42	- 0.2 40	- 0.1 24
	Zs	- 0.0 47	0.8 83	- 0.91 4	0. 75 9	0.6 35	0.3 56	0.1 09	- 0.6 04	2.1 85*	- 0.1 70	- 0.2 63	- 0.3 56
	Qmed	- 0.0 22	0.3 06	- 0.81 1	1. 17 5	0.3 13	0.0 70	0.0 07	- 0.0 94	0.2 84	- 0.2 05	- 0.1 87	- 0.2 59
Marsabit Central	ACF	- 0.2 46	- 0.0 69	0.14 9	- 0. 16 5	0.0 17	- 0.1 99	- 0.2 44	- 0.0 15	- 0.0 01	- 0.0 11	- 0.3 38	- 0.1 11
	Zs	- 1.0 07	0.2 01	- 0.48 0	0. 13 9	0.9 76	- 0.4 18	- 0.0 78	- 0.2 17	0.4 18	1.9 68*	0.8 83	- 0.9 14
	Qmed	- 0.0 48	0.0 15	- 334 2.00 0	0. 36 9	0.6 85	- 0.0 41	- 0.0 03	- 0.0 09	0.0 20	3.0 83	1.3 53	- 0.6 91
Marsabit North	ACF	- 0.2 88	- 0.0 28	- 0.24 8	- 0. 03 9	- 0.0 56	0.1 20	0.1 23	0.0 10	- 0.0 50	- 0.0 68	- 0.1 84	- 0.2 75
	Zs	1.1 00	0.8 84	0.17 0	1. 25 5	- 0.8 21	- 0.1 09	0.2 32	2.3 40*	0.0 16	- 0.6 35	- 0.4 80	- 0.7 28
	Qmed	0.1 14	0.0 76	0.06 4	0. 88 8	- 0.1 16	- 0.0 01	0.0 03	0.0 33	0.0 00	- 0.0 41	- 0.0 60	- 0.0 86
Sololo	ACF	- 0.1 38	- 0.0 43	0.00 0	- 0. 41 9	- 0.0 76	- 0.0 85	- 0.1 25	- 0.0 62	0.0 41	- 0.2 01	- 0.3 02	- 0.1 36
	Zs	- 51 13. 00 0	0.1 70	0.23 2	1. 67 03 *	0.7 59	- 1.0 07	- 1.1 00	0.8 21	0.5 11	0.9 14	0.8 52	- 0.6 97
	Qmed	- 0.0 43	0.0 23	0.10 3	1. 48 8	0.5 52	- 0.0 54	- 0.0 37	0.0 52	0.0 24	0.5 66	0.5 33	- 0.2 11
North Horr	ACF	- 0.1 93	- 0.1 19	0.00 2	- 0. 27	- 0.0 71	- 0.2 21	0.0 41	0.1 22	- 0.0 47	0.2 03	- 0.2 13	- 0.2 64

					1								
Zs	-0.356	0.170	-0.449	0.139	0.697	0.759	0.263	-1.131	0.542	-1.255	-1.007	-0.047	
Qmed	-845.000	0.027	-0.188	0.092	0.096	0.082	0.047	-0.123	0.034	-0.264	-0.477	-0.024	

ACF = Autocorrelation Coefficient; Zs = Mann-Kendall trend test; Qmed = Theil-Sen's slope; * = significant at 10%; ** = significant at 5%; and *** = significant at 1%. Bold numbers indicate presence of serial correlation, but it was successfully eliminated

Figure 1: Decomposition of Additive Time Series for Precipitation in Marsabit County from 1990 to 2022



3.2 Trend Analysis of Maximum Temperature in Marsabit County from 1990 to 2022

The analysis of maximum temperature data for Marsabit County shows statistically significant ($p \leq 0.05$) warming in July, September and December from 1990 to 2022 (Table 2). In Moyale, the statistically significant ($p \leq 0.05$) warming was observed in August. The months observed to have statistically significant ($p \leq 0.05$) increase in temperature in Marsabit South were January, August, September, and December. In Marsabit Central, the months of January, February, March, September, November and December experienced statistically significant warming. In North Horr, the months of January, July, September and December experienced statistically significant ($p \leq 0.05$) increase in temperature in the study period. Similar results were obtained in Figure 2,

which shows an increasing maximum temperature trend in Marsabit County from 1990 to 2022.

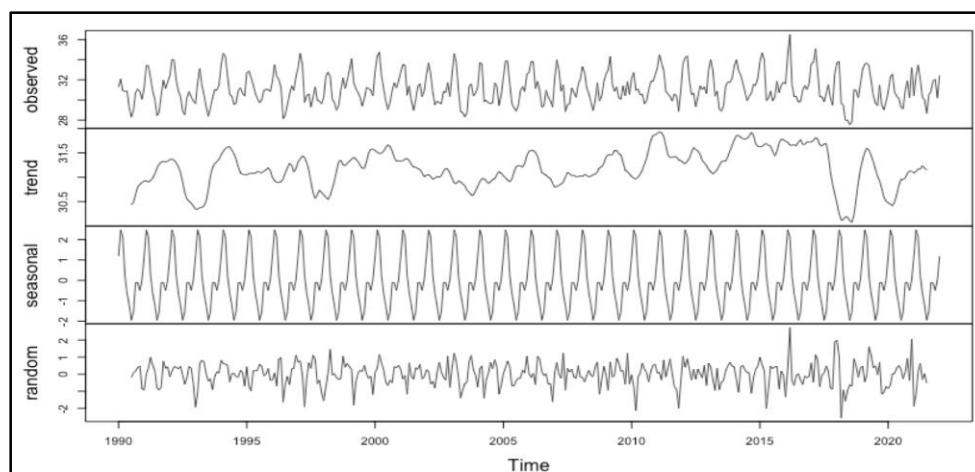
Table 2: Trend Analysis of Monthly Mean Maximum Temperature in Marsabit County from 1990 to 2022

A R E A		J A N	F E B	M A R	A P R	M A Y	J U N	J U L	A U G	S E P	O C T	N O V	D E C
County	ACF	0.028	-0.065	-0.104	-0.388	-0.020	-0.170	-0.061	0.087	0.196	-0.124	0.057	-0.471
	Zs	1.379	0.604	1.379	0.114	-0.449	1.410	1.9368**	1.7199*	2.681***	-0.387	0.325	2.319**
	Qmed	0.028	0.008	0.030	0.004	-0.002	0.024	0.025	0.023	0.018	-0.005	0.006	0.050
Moyale	ACF	0.060	-0.030	-0.071	-0.222	-0.079	0.062	0.075	0.451	0.268	-0.124	0.215	-0.256
	Zs	0.821	0.139	1.503	0.573	0.852	0.945	1.627	3.033***	1.844*	-0.418	0.573	1.286
	Qmed	0.024	0.002	0.034	0.007	0.016	0.018	0.032	0.034	0.020	-0.008	0.013	0.040
Loiyangalani	ACF	0.176	0.374	-0.047	-0.108	0.066	-0.238	0.205	-0.015	0.107	-0.018	-0.074	-0.215
	Zs	0.480	-0.568	0.047	0.294	-0.139	1.100	1.503	0.434	-1.426	-0.883	-1.255	0.016
	Qmed	0.004	-0.011	0.005	0.012	-0.007	0.047	0.043	0.014	-0.024	-0.022	-0.037	0.001
Marsabit South	ACF	0.285	0.164	-0.050	-0.340	0.105	-0.064	0.043	0.220	0.291	0.120	0.074	-0.032
	Zs	2.247*	0.170	1.162	0.170	-1.162	0.759	1.007	2.959***	2.634***	0.666	1.224	2.990***
	Qmed	0.035	0.003	0.029	0.007	-0.023	0.011	0.023	0.044	0.029	0.012	0.018	0.046
Marsabit Central	ACF	0.092	0.041	-0.035	-0.085	0.073	0.188	0.445	0.418	0.691	0.092	0.159	0.011
	Zs	2.928**	4.013**	2.743**	1.6889*	1.472	1.7509*	1.346	1.131	1.962**	0.759	2.402*	3.580***

	Qmed	0.070	0.059	0.074	0.052	0.036	0.035	0.040	0.020	0.050	0.014	0.043	0.083
Marsabit North	ACF	0.082	-0.042	-0.085	-0.243	0.093	-0.065	0.046	0.025	0.236	0.365	0.038	- 0.487
	Zs	1.224	0.201	0.217	-1.007	-1.348	0.558	0.294	1.705*	1.302	-2.509**	-1.162	-0.049
	Qmed	0.031	0.006	0.006	-0.023	-0.029	0.006	0.002	0.017	0.013	-0.028	-0.022	-0.001
Sololo	ACF	-0.130	-0.073	-0.034	- 0.409	0.041	0.095	0.081	0.262	0.519	-0.229	0.342	- 0.417
	Zs	0.790	-0.449	1.038	0.438	1.131	0.170	0.604	1.751*	0.860	-0.403	0.434	1.249
	Qmed	0.022	-0.009	0.029	0.007	0.023	0.006	0.010	0.032	0.011	-0.004	0.008	0.029
North Horr	ACF	0.133	-0.065	-0.185	-0.326	-0.123	-0.020	-0.029	0.570	0.365	-0.245	0.086	-0.175
	Zs	2.339*	1.875*	1.503	0.016	-0.728	1.348	2.0608**	0.924	2.903***	0.016	0.403	2.681***
	Qmed	0.038	0.027	0.028	0.000	-0.013	0.031	0.029	0.013	0.031	0.000	0.007	0.051

ACF = Autocorrelation Coefficient; Zs = Mann-Kendall trend test; Qmed = Theil-Sen's slope; * = significant at 10%; ** = significant at 5%; and *** = significant at 1%. Bold numbers indicate presence of serial correlation, but it was successfully eliminated

Figure 2: Decomposition of Additive Time Series for Maximum Temperature in Marsabit County from 1990 to 2022



3.3 Trend Analysis of Minimum Temperature in Marsabit County from 1990 to 2022

The trend analysis of monthly mean minimum temperature in Marsabit County from 1990 to 2022 is provided in Table 3. The analysis reveals that the increase in minimum temperature was statistically significant ($p \leq 0.05$) in August, September and October. In Moyale, the month of July had statistically significant ($p \leq 0.05$) increase in minimum temperature. The months of September and October were found to have been significantly ($p \leq 0.05$) warming in Loiyangalani and Marsabit South. In Marsabit Central the minimum temperature was observed to be significantly ($p \leq 0.05$) increasing in the months of February, March, April and December. The months of July, August, September and October were observed to have increasing minimum temperature in Sololo from 1990 to 2022. In Figure 3, similar results were obtained using the decomposition of additive time series for minimum temperature in Marsabit County from 1990 to 2022.

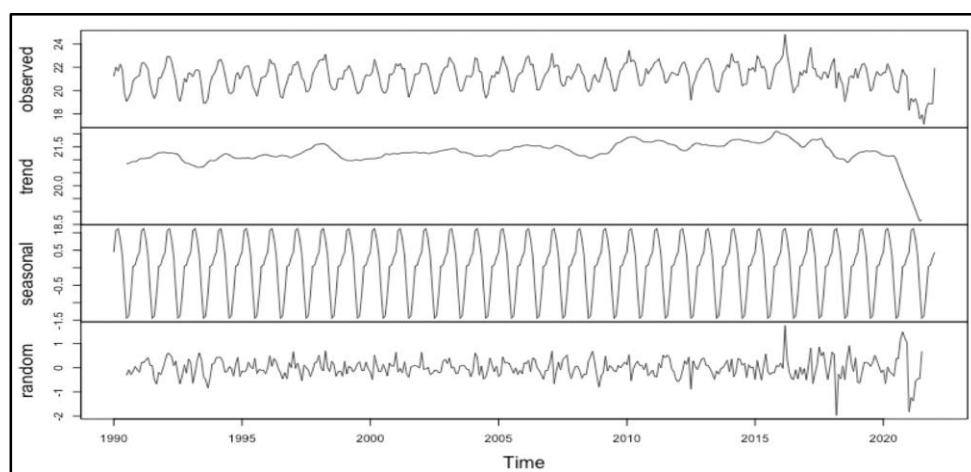
Table 3: Trend Analysis of Monthly Mean Minimum Temperature in Marsabit County from 1990 to 2022

AREA		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
County	A C F	- 0.0 27	0.0 76	- 0.05 3	- 0.16 3	- 0.04 9	0.2 23	0.0 01	0.35 0	0.3 78	0.15 1	0.06 7	- 0.0 48
	Z s	0.4 49	1.0 69	0.91 4	0.00 2	1.22 4	1.4 41	1.3 17	2.22 2**	3.3 57* **	3.20 7***	1.00 7	1.8 13*
	Q m e d	0.0 03	0.0 15	0.01 0	0.00 0	0.01 1	0.0 15	0.0 11	0.02 2	0.0 24	0.02 4	0.00 8	0.0 15
Moyale	A C F	0.0 21	0.1 65	- 0.13 8	- 0.23 0	- 0.11 5	0.2 28	0.1 67	0.54 8	0.3 64	0.14 6	0.42 7	0.1 14
	Z s	- 0.4 65	1.5 34	1.06 9	- 0.57 3	1.31 7	1.4 72	2.4 636 **	1.18 4	0.4 70	0.75 9	- 0.24 3	1.7 20*
	Q m e d	- 0.0 04	0.0 16	0.01 3	- 0.00 7	0.01 2	0.0 16	0.0 25	0.01 0	0.0 05	0.00 6	- 0.00 2	0.0 20
Loiyang alani	A C F	- 0.0 65	- 0.0 90	- 0.05 9	- 0.23 4	- 0.18 9	0.0 30	- 0.1 52	0.08 8	0.1 24	0.00 6	- 0.06 1	- 0.1 23
	Z s	0.0 00	0.4 80	0.13 9	0.38 7	0.31 0	0.4 49	0.5 73	1.27 1	3.4 24* **	2.21 6**	0.26 3	0.0 47
	Q m	0.0 00	0.0 07	0.00 4	0.00 5	0.00 4	0.0 03	0.0 08	0.01 3	0.0 51	0.02 5	0.00 3	0.0 02

	ed												
Marsabit South	ACF	0.137	0.366	0.271	0.376	0.362	0.474	0.369	0.468	0.440	0.269	0.068	0.000
	Zs	0.000	0.114	0.170	-0.600	-0.049	-0.373	-0.341	0.178	3.033**	2.495***	0.992	1.038
	Med	0.000	0.004	0.003	-0.009	-0.001	-0.005	-0.009	0.005	0.037	0.029	0.010	0.010
Marsabit Central	ACF	0.483	0.387	0.173	0.341	0.372	0.479	0.755	0.756	0.770	0.733	0.643	0.605
	Zs	1.022	2.124**	3.920***	2.277**	1.8649*	1.7027*	0.730	1.703*	1.703*	1.443	1.216	2.351**
	Med	0.016	0.030	0.042	0.034	0.026	0.021	0.013	0.020	0.020	0.020	0.020	0.029
Marsabit North	ACF	0.218	0.348	0.193	0.251	0.256	0.463	0.298	0.452	0.441	0.454	0.542	0.285
	Zs	0.263	-0.470	-0.325	-1.286	-0.511	-0.535	0.170	1.119	0.665	-0.568	-1.119	0.279
	Med	0.006	-0.013	-0.010	-0.022	-0.006	-0.009	0.004	0.015	0.008	-0.006	-0.014	0.004
Sololo	ACF	0.090	0.082	-0.230	-0.236	-0.194	0.137	0.194	0.349	0.284	0.015	0.051	-0.136
	Zs	-0.542	1.255	0.883	0.325	1.6269*	1.302	2.324**	2.643***	1.999*	2.805***	0.573	1.720*
	Med	-0.010	0.019	0.019	0.005	0.018	0.018	0.026	0.028	0.020	0.019	0.006	0.021
North Horr	ACF	0.209	0.237	0.293	0.321	0.304	0.381	0.190	0.366	0.411	0.419	0.399	0.247
	Zs	0.372	0.976	0.604	-0.682	0.418	-0.146	-0.201	0.730	0.957	0.211	-0.470	0.852
	Med	0.006	0.014	0.010	-0.007	0.003	-0.002	-0.004	0.016	0.011	0.002	-0.007	0.014

ACF = Autocorrelation Coefficient; Zs = Mann-Kendall trend test; Qmed = Theil-Sen's slope; * = significant at 10%; ** = significant at 5%; and *** = significant at 1%. Bold numbers indicate presence of serial correlation, but it was successfully eliminated

Figure 3: Decomposition of Additive Time Series for Minimum Temperature in Marsabit County from 1990 to 2022



3.4 Short Rain and Long Rain Seasons in Marsabit County from 1990 to 2022

The precipitation and temperature data for Marsabit County was analysed for trends during the short-rain and long-rain seasons. Table 4 shows statistically significant ($p \leq 0.05$) increase during in minimum temperature during the long-rain season. However, precipitation and maximum temperature during the season were found to be decreasing albeit not significantly. The results show non-significant decline in precipitation during the short-rain season. Similar results were observed for the maximum and minimum temperature during the season. The maximum temperature for Moyale was observed to have increased significantly ($p \leq 0.05$) during the long-rain season. The results show that maximum temperature in Marsabit South had significantly ($p \leq 0.05$) increased during the short-rain season in Marsabit South. The Marsabit Central experienced a significant increase in maximum and minimum temperature during the long-rain season as well as increased maximum temperature during the short-rain season. The minimum temperature in both short-and long-rain seasons had significantly ($p \leq 0.05$) increased from 1990 to 2022.

Table 4: Trend Analysis of Short-Rain and Long-Rain Seasons in Marsabit County from 1990 to 2022

AREA		LONG-RAIN SEASON (March-April-May)			SHORT-RAIN SEASON (October-November-December)		
	Test	Precipitation	Maximum Temperature	Minimum Temperature	Precipitation	Maximum Temperature	Minimum Temperature
County	ACF	$\bar{-}$ 0.188	-0.307	0.051***	$\bar{-}$ 0.376	-0.341	-0.098
	Zs	0.573	0.945	2.743	0.243	1.317	1.472
	Qmed	0.242	0.009	0.015	0.097	0.017	0.011
Moyale	ACF	$\bar{-}$ 0.219	-0.210	-0.176	$\bar{-}$ 0.324	-0.184	0.415
	Zs	$\bar{-}$ 0.016	2.061**	1.379	$\bar{-}$ 0.016	1.286	0.243
	Qmed	$\bar{-}$ 0.013	0.025	0.010	$\bar{-}$ 0.033	0.013	0.002
Loiyangalani	ACF	$\bar{-}$ 0.219	-0.076	-0.192	$\bar{-}$ 0.324	-0.098	-0.075
	Zs	$\bar{-}$ 0.016	0.511	0.232	$\bar{-}$ 0.016	-1.379	1.627
	Qmed	$\bar{-}$ 0.013	0.010	0.001	$\bar{-}$ 0.033	-0.035	0.014
Marsabit South	ACF	$\bar{-}$ 0.136	-0.188	0.403	$\bar{-}$ 0.235	0.051	0.142
	Zs	0.449	0.635	-0.211	$\bar{-}$ 0.449	2.2467**	1.534
	Qmed	0.343	0.014	-0.002	$\bar{-}$ 0.299	0.025	0.017
Marsabit Central	ACF	$\bar{-}$ 0.050	-0.066	0.302	$\bar{-}$ 0.269	0.151	0.700
	Zs	0.047	2.526***	3.579***	0.945	2.959***	1.443
	Qmed	0.047	0.056	0.040	1.036	0.044	0.016
Marsabit North	ACF	$\bar{-}$ 0.083	-0.081	0.290	$\bar{-}$ 0.296	-0.066	0.478
	Zs	0.263	-0.511	-0.170	$\bar{-}$ 0.728	-1.410	-0.470
	Qmed	0.079	-0.019	-0.004	$\bar{-}$ 0.109	-0.019	-0.005
Sololo	ACF	$\bar{-}$ 0.114	-0.215	-0.255	$\bar{-}$ 0.300	-0.186	-0.037
	Zs	0.945	1.7508*	1.875**	0.821	0.511	2.123**
	Qmed	0.405	0.029	0.015	0.334	0.011	0.016
North Horr	ACF	$\bar{-}$ 0.209	-0.391	0.324	$\bar{-}$ 0.280	-0.355	0.368

	Zs	-0.356	0.114	0.697	-0.790	1.833*	0.049
	Qmed	-0.080	0.005	0.009	-0.243	0.022	0.000

ACF = Autocorrelation Coefficient; Zs = Mann-Kendall trend test; Qmed = Theil-Sen's slope; * = significant at 10%; ** = significant at 5%; and *** = significant at 1%. Bold numbers indicate presence of serial correlation, but it was successfully eliminated

3.5 Trend Analysis of Mean Annual Precipitation and Temperature in Marsabit County from 1990 to 2022

The trend analysis was conducted for mean annual precipitation, maximum and minimum temperature (Figure 5) in data. According to the results, the mean annual maximum and minimum temperature for the Marsabit County were found to be significantly ($p \leq 0.05$) increasing while mean annual precipitation was declining, though not significantly, in the study period. In Moyale, the mean annual maximum and minimum temperature were observed to have significantly ($p \leq 0.05$) increased. The mean annual precipitation and minimum temperature have significantly ($p \leq 0.05$) increased in Loiyangalani. Marsabit South, Marsabit Central, North Horr have also experienced a statistically significant ($p \leq 0.05$) increase in mean annual maximum temperature from 1990 to 2022. The mean annual maximum and minimum temperature were also found to have significantly increased in Sololo during the study period.

Table 5: Trend Analysis of Annual Mean Precipitation and Temperature in Marsabit County from 1990 to 2022

Area	Precipitation			Maximum Temperature			Minimum Temperature		
	ACF	Zs	Qmed	ACF	Zs	Qmed	ACF	Zs	Qmed
County	-0.014	0.852	0.162	0.074	2.588**	0.018	0.095	3.083**	0.020
Moyale	-0.162	-0.139	-0.032	0.237	2.588**	0.022	0.308	2.619**	0.016
Loiyangalani	0.245	2.402**	0.553	0.276	0.201	0.003	-0.083	2.123*	0.013

Marsabit South	0.136	-0.232	-0.079	0.261	2.247* *	0.021	0.449	0.568	0.007
Marsabit Central	0.032	0.635	0.200	0.310	3.827* **	0.047	0.707	1.476	0.011
Marsabit North	0.019	-0.387	-0.051	0.235	0.418	0.005	0.461	0.957	0.003
Sololo	-0.042	0.883	0.173	0.248	1.937* *	0.024	0.009	3.083* **	0.019
North Horr	0.128	-1.162	-0.194	-0.043	2.526* **	0.025	0.387	1.087	0.007

ACF = Autocorrelation Coefficient; Zs = Mann-Kendall trend test; Qmed = Theil-Sen's slope; * = significant at 10%; ** = significant at 5%; and *** = significant at 1%.

Bold numbers indicate presence of serial correlation, but it was successfully eliminated

3.6 Discussion

The trend of the mean annual rainfall in Marsabit County, though not statistically significant, has been declining. In the seasonal analysis, it has been revealed that precipitation in both the short-rain and long-rain seasons has been declining. The results compare with reviewed literature that rainfall patterns in Marsabit County have shown a decreasing trend over the years, with prolonged dry spells and erratic rainfall distribution (Wato et al. 2022; Galwab, 2023; Gudere et al., 2023).

The study also established that mean annual precipitation in different sub-counties was varied. In Moyale and Sololo, there was decline in precipitation whereas in Loiyangalani, Marsabit South, Marsabit Central, Marsabit North, and North Horr the rainfall had an increasing trend. However, the only significant trend was observed in Loiyangalani. The variation may be explained the existence of four agroecological zones (i.e. III, IV, V & VI) in Marsabit County (Government of Kenya, 2018).

There has been significantly upward trend in mean annual maximum and minimum temperature in Marsabit County. The literature on climate change in the study area confirm the findings that the climate in the county is warming (County Government of Marsabit, 2023; Gudere et al., 2023). Other studies show a shift in rainfall patterns, temperature, and wind distribution in the region over the past few decades (Cuní-Sanchez et al., 2018).

4. Conclusion

The paper examines monthly, seasonal, and annual trends of precipitation, maximum temperature and minimum temperature in the County of Marsabit from 1990 to 2022. It has been revealed that there is a decline in precipitation and increase in both maximum temperature and minimum temperature in the county. However, there are variations across the sub-counties. These trend demonstrate that while temperature is increasing with time, the rainfall does not follow the same trend.

The increasing temperature and declining precipitation in Marsabit County might be indicative of broader climate change trends affecting the North Eastern region of Kenya. These changes could have significant impacts on local ecosystems, agriculture, and water availability, potentially leading to challenges for Gabbra community who are reliant on pastoralism for their livelihoods.

The study makes the following conclusions:

- The pastoral areas of Gabbra community in Marsabit County have been experiencing a statistically significant increase in annual temperature trends from 1990 to 2022.
- Moyale and Sololo have been experiencing a downward but non-significant precipitation trend whereas in Marsabit South, Marsabit Central and North Horr the rainfall has been having an upward but non-significant trend. However, the precipitation in Loiyangalani has been having a significantly increasing trend.
- The annual precipitation trends from 1990 to 2022 have been declining albeit the change is not statistically significant.
- The annual maximum temperature in all the Marsabit sub-counties inhabited by the Gabbra community has been significantly increasing except for Loiyangalani and Marsabit Central.
- Moyale, Loiyangalani and Sololo have been experiencing a significant increase in trend for annual minimum temperature. However, the upward trend for minimum temperature in Marsabit South, Marsabit Central, Marsabit North and North Horr is not statistically significant.

5. Policy Recommendations

Based on this study, the following policy recommendations have been made:

1. The reduction in monthly, seasonal and annual precipitation experienced in Marsabit County should prompt the livestock sector to initiate climate resilience programs to ensure sustainable livelihoods.
2. This study recommends exploitation of groundwater resource to supplement the limited surface water resources in the face of declining precipitation during the short-rain and long-rain seasons in Marsabit County.

3. There is need for long-term adaptation strategies, such as the construction of water harvesting dams, to mitigate impacts such as those on livelihoods.
4. The declining precipitation coupled with increasing temperature might affect pasture in the grazing lands of Gabbra communities. There is need for reseeded the Gabbra rangelands to guarantee adequate grass for livestock.

Acknowledgement: The authors wish to thank the research participants for their support and participation. Special appreciation also goes to the Kenya Meteorological Department for providing the climate data used in this study.

Disclosure Statement: Conflict of Interest: The authors declare that there are no conflicts of interest. Compliance with Ethical Standards: This article does not contain any studies involving human or animal subjects.

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