Rainfall and Temperature Trends and Variability in Arid and Semi-arid Lands of Kitui County, Kenya

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Abstract

A study was carried out to analyse rainfall and temperature trends and variability in selected agro-ecological zones in Kitui County. Climate Hazards Group Infrared Precipitation with Stations (CHIRPS) rainfall dataset was used while temperature data was obtained from the Climatic Research Unit gridded Time Series (CRU TS) dataset. The results indicated that there was a non-significant decreasing trend ($p<0.05$) in average annual rainfall in all the four agro-ecological zones ($p<0.05$) for a 30-years period (1988-2018) in the study area. A decreasing trend in March-April-May (MAM) seasonal rainfall trend was reported in the arid and semi-arid agro-ecological zones while an increasing trend was recorded in the transitional and semi-humid zones. For the October-November-December (OND) seasonal rainfall, a non-significant decreasing trend was reported in all the four agro-ecological zones. Additionally, a higher annual rainfall variability was recorded in the drier (arid) and wetter (semi-humid) zones compared to that in semi-arid and transitional zones. Moreover, the study established that there was a spatial variation in both MAM and OND seasonal rainfall variability and that rainfall variability was higher in the OND seasonal rainfall than that of the MAM seasonal rainfall in all the agro-ecological zones. With reference to temperature trends, a statistically significant increasing trend in annual and OND seasonal average maximum and minimum temperatures was reported in all the four agro-ecological zones. Further, the study noted a non-significant increasing trend in maximum and minimum temperatures for the MAM season in all the agro-ecological zones. In regard to temperature variability, the study deduced that there was low temperature variability compared to rainfall variability in all the four agro-ecological zones. The study recommends that location-specific rainfall and temperature analysis should guide planning and implementation of adaptation strategies for effective response to climate variability.

Keywords: Agro-ecological Zones, Mann-Kendall Test, Coefficient of Variation, CHIRPS, CRU TS
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1. Introduction

Climate variability has been observed throughout history resulting from natural internal variations in the climate system and anthropogenic activities. Scientific evidence has however associated the current warming of the Earth to the increased accumulation of greenhouse gases from fossil fuels as well as the destruction of carbon sinks by humans (IPCC, 2014). Climate projection models by the IPCC indicate that global mean surface temperature will increase by a range of 1.4°C to 5.8°C from the current to 2100, with the range being influenced by the rate of emissions from fossil fuels combustion between the present and then as well as on different projection models utilized (McCarthy *et al.,* 2001). According to Niang *et al.* (2014), '*very likely'* reductions in annual rainfall were reported in most parts of Africa with a general decrease in the 20th century being experienced over the Sahel with 0.5°C rise in near-surface temperatures being reported over the past century in most African countries. Further, projections have shown that warmer temperatures are expected to occur in the East African region with a 5% to 20% increase in rainfall from December-February and a 5% to 10% reduction from June to August by 2050 (Hulme *et al.,* 2001). Similarly, Marigi et *al.* (2016) reported declining patterns in annual precipitation, the intensity of precipitation, successive moisture periods and increasing trends in successive days without moisture as well as constant rising temperature trends for both the maximum and minimum temperature index values in Arid and Semi-arid Lands of South Eastern Kenya.

Variations in the temperature and rainfall patterns are likely to increase the intensity and frequency of extreme climate events, such as heavy precipitation, floods and droughts which would have adverse impacts on global agricultural production (IPCC, 2007).Kenya has been rated as one of the highly vulnerable countries to climate variability and extreme events in Africa owing to her reliance on sectors such as agriculture and fisheries that are highly sensitive to climatic changes as the main drivers of the economy coupled with limited adaptive capacity (FAO, 2011; Herrero *et al.,* 2010; Kabubo-Mariara and Karanja, 2007) and therefore variations in temperature and rainfall are likely to have disastrous impacts on community livelihoods in ASALs (Easterling *et al.,* 2007; FAO, 2011). Since precipitation and temperature are two of the most important climate variables in the field of climate sciences and hydrology that are frequently used to trace the extent and magnitude of climate change and variability (IPCC, 2007), prediction of temperature and precipitation trends is crucial in informing policies on planned adaptation to climate change and variability in order to reduce households' vulnerability. The present study therefore sought to analyze rainfall and temperature trends and variability in four agro-ecological zones in Kitui County.

2. Materials and Methods

2.1 Profile of the study area

The study was carried out along a transect line (in a buffer zone of 5km radius on both sides of the line) in four agro-ecological zones namely; semi-humid, transitional semi-humid to semi- arid, semi-arid and arid zones in Kitui County, which were classified using the Jaetzold *et al.* (1983) categorization of agro-ecological zones. The study sites are shown in Figure 1. Kitui County lies between 400m to 1,830m above sea level and generally slopes from the west to east with the highest regions being Kitui Central and Mutitu Hills (KCIDP, 2018). The climate of the area is semi-arid with very erratic and unreliable rainfall. The area is hot and dry throughout the year with temperatures ranging from a minimum of 14-22° centigrade to a maximum of 26-34° centigrade.

February and September are the hottest months in the year (KCIDP, 2018). Rainfall is distributed within two seasons annually locally referred to as "long rains" and "short rains" that varies from 500-1050mm with about 40% reliability. The "long rains" are experienced between March and May and "short rains" between October and December. The "short rains" are considered more reliable than the "long rains" since it is during the "short rains" that farmers get their main food production opportunity (NDMA, 2017). The area consists of a variety of soil types ranging from sandy to black cotton which are generally low in fertility rates (GoK, 2005).

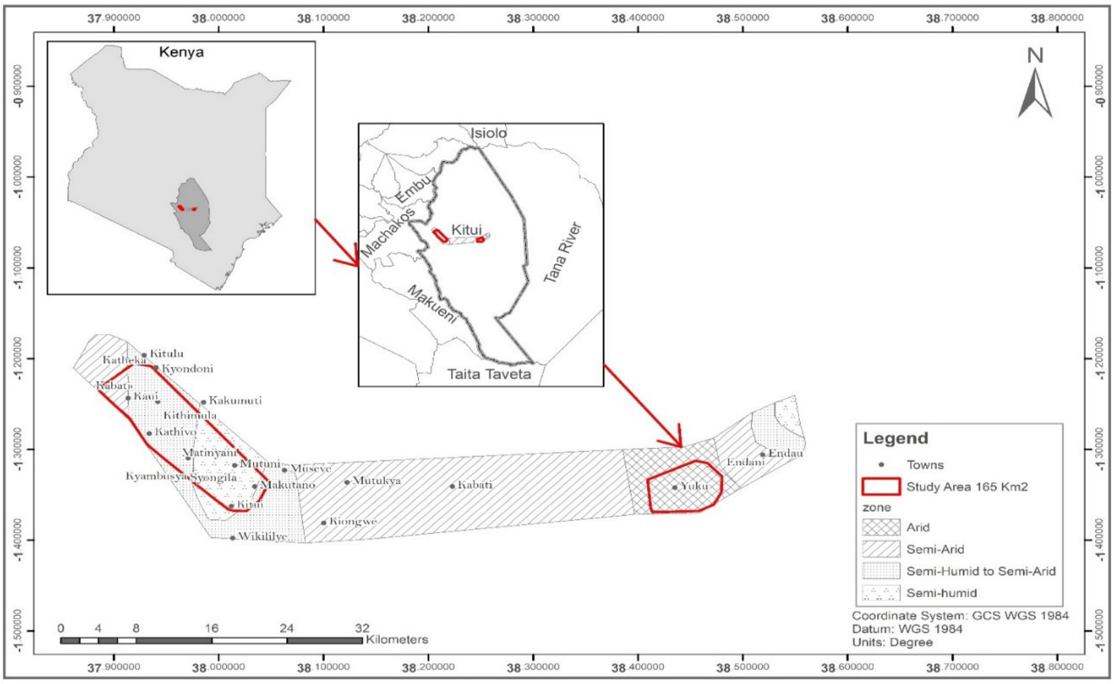

Figure 1. Map of Kitui County showing the study area in four agro-ecological zones
Source: ILRIS GIS Database

2.2 Data Collection and Analysis

The Climate Hazards Group Infrared Precipitation with Stations (CHIRPS; CHIRPS v2.0 at 0.05° horizontal resolution; 1981–near present; Funk *et al*. 2015) rainfall dataset was used. CHIRPS database is a useful set of precipitation data for studying precipitation patterns and drought monitoring, with a long-time series (more than 30 years) and high spatial resolution and provides a practical alternative in the absence of ground precipitation data (Bai *et al.,* 2018; Funk *et al.,* 2015; Habitou *et al.,* 2021; Zambrano *et al.,* 2016). CHIRPS database comprises a quasi-global (50°S-50°N, 180°E-180° W), 0.05° resolution, 1981 to near present gridded precipitation time series and merges three types of information: global climatology, satellite estimates, and in situ observations generating several precipitation products with time steps from 6-hourly to 3-monthly aggregates (Bai *et al.,* 2018; Funk *et al.,* 2015).

In comparison with other precipitation data sets such as the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN-CDR), which provides daily rainfall estimates at a spatial resolution of 0.25 degrees in the latitude band 60S - 60N from 1983 to the near-present and Tropical Rainfall Measuring Mission (TRMM3B43), which provides a "best" precipitation estimate by merging merged microwave-infrared precipitation rate (in mm/hr) and root-mean-square (RMS) precipitation-error estimates, Zambrano *et al.* (2016) reported that CHIRPS datasets showed the best agreement with ground precipitation measurements in Chile. Similarly, Le and Pricope (2017) reported that CHIRPS dataset had a greater temporal correlation with the in situ station data in Nzoia Basin, Western Kenya. CHIRPS datasets have been used to analyze precipitation trends in similar studies in East Africa (Aduma *et al.,* 2018; Cattani *et al.,* 2021; Gebrechorkos *et al.,* 2019; Kerandi *et al.,* 2017).

The gridded Climate Research Unit (CRU v3.24, monthly at 0.5° horizontal resolution, 1901 to 2014; Harris *et al.* 2014) temperature dataset was used. The CRU dataset provides a high-resolution resolution (0.5° × 0.5°), a monthly grid of land-based observations for several climate variables including minimum and maximum temperature (Harris et *al.,* 2014, 2020). Harris et *al.* (2020) reported a high correlation of the majority of interpolated global monthly temperature anomalies with station observations. In addition, Mahmood and Jia (2017) reported a high correlation between CRU data and in situ observed data using different statistical indicators indicating that CRU data could be utilized with high certainty. Similar studies have used CRU TS data to analyze temperature trends in Kenya (Ayugi *et al.,* 2018; Kerandi *et al.,* 2017; Ouma *et al.,* 2018).

Annual and seasonal rainfall and temperature trends for a period of 30 years (1988-2018) in the study area were analyzed using the Mann-Kendall (MK) statistical test.

The Mann-Kendall Statistic (S) is a non-parametric statistical process for assessing the trends of data sets over time, with positive (+) values indicating an increase in element concentration over time and negative (-) values indicating a drop in element values in a given period (Kendall, 1975; Khambhammettu, 2005; Mann, 1945; Opiyo *et al.,* 2014).

The Mann-Kendal Test was used for this study for trend analysis since it does not require the assumption of residual normality as it is the case in linear regression method (Kendall, 1975; Mann, 1945). According to Viessman *et al.* (1989), hydrological variables show a pronounced right skewedness and do not adopt a normal distribution due to the influence of natural phenomena. The non-parametric test is thus preferred for trend analysis in time series over parametric tests since it evades the problem caused by data skewness (Aditya *et al.,* 2021; Mondal *et al.,* 2012; Opiyo, *et al.,* 2014).

The MK statistic (S) refers to the overall outcome of all the increases and decreases i.e the summation of all the positive differences excluding the aggregate negative variances (Khambhammettu, 2005) as shown in the following equation;

$$S = \sum_{k-1}^{n-1} \sum_{k=j+1}^{n} Sign(x_j - x_k) \quad (1)$$

Where, $x_1 \dots x_n = n\ data\ values,\ J_x = data\ value\ at\ time_j$, $sign\ (x_j - x_k) = 1\ if\ (x_j - x_k) > 0$, $= 0\ if (x_j - x_k) = 0\ and - 1\ if\ (x_j - x_k) < 0$

The Kendall Test (Kendall, 1975) was used to predict a normal-approximation assessment for large amounts of data with more than ten values to account for the non-monotonic identity of patterns in the data; the testing is applied using a normal distribution (Helsel and Frans, 2006; Khambhammettu, 2005) with the mean and variance by first determining S as described in Equation 1 and then

The variance of S is calculated, $VAR(S)$ using Equation 2

$$VAR(S) = \frac{1}{8}\left[n(n-1)(2n+5) - \sum_{p=1}^{g} t_p(t_p - 1)(2t_p + 5)\right] \quad (2)$$

Where $n =$ number of data points,

g = the number of tied groups, (a tied group is a set of sample data having the same value) and

$p\ t$ = the number of data points in the p^{th} group.

In the sequence {2, 3, non-detect, 3, non-detect, 3}, we have $n = 6$, $g = 2$, $1t = 2$ for the non-detects, and $2t$=3 for the tied value 3.

The standard normal deviate (Z statistics) is then computed as *(Khambhammettu, 2005)* follows:

$$Z = \frac{S-1}{\left[VAR(S)^{\frac{1}{2}}\right]}\ if\ S > 0 \quad (3)$$

$$= 0\ if\ S = 0$$

$$= \frac{S+1}{\left[VAR(S)^{\frac{1}{2}}\right]} \; if \text{ S<0}$$

To calculate the probability linked with the normalized test statistics, the probability density function for a normal distribution is expressed in Equation 4:

$$f(Z) = \frac{1}{\sqrt{2\pi}} e^{\frac{-Z^2}{2}} \quad (4)$$

From the above equations, a negative Z score with a calculated probability greater than the significant level indicates a declining trend, whereas a positive Z score with a calculated probability larger than the significant level indicates an increasing trend. If the estimated probability is lower than the significant level of significance, then there is no trend in the data points (Khambhammettu, 2005; Opiyo *et al.,* 2014).

The Sen's slope estimator was used to model the linear trends (Sen, 1968) since it does not require the assumption of residual normality like the linear regression method (McBean and Motiee, 2008).

The Sen's slope was therefore determined to be the mean of all pair-wise slopes for any pair of points in the dataset where the following equation was used to estimate each individual slope

$$(m_{ij}) = \frac{Y_j - Y_i}{j - 1} \quad (5)$$

Where, $i = 1 \; to \; n - 1, j = 2 \; to \; n, Y_j \; and \; Y_j$ are data values at time j and $i(j > i)$, respectively.
If in the time series there are n values of Y_j , estimates of the slope will be

$$N = \frac{n(n-2)}{2} \quad (6) .$$

The slope of the Sen Estimator is the mean slope of such slopes N values.

The Sen's slope is: $$m = \begin{cases} m\left[\frac{N+1}{2}\right] & \text{if n is odd} \\ \frac{1}{2}\left[m_{\frac{N}{2}} + m_{\frac{N+2}{2}}\right] & \text{if n is even} \end{cases} \quad (7)$$

The coefficient of variation (CV) was used to calculate the variability of annual and seasonal rainfall and temperature for a period of 30 years (1988-2018) in the study area. According to Araya and Stroosnijder (2011), a coefficient of variation larger than 30% indicates high variability.

3. Results

3.1 Annual rainfall trend in the study area

Mann-Kendall statistical test results for total annual rainfall for a period of 30 years (1988–2018) had a negative Z-statistics value implying a decreasing trend in the annual precipitation in the four agro-ecological zones as shown in Table 1. The findings however indicated that the trend was not significant at 5% significance level. Additionally, the Sen's slope estimator values indicated that the arid zone had the highest amount of rainfall decrease per year (6.59 mm), followed by semi-arid (4.59 mm) and transitional (3.96 mm) zones while the semi-humid zone had the lowest (3.93 mm). Further, the results revealed that the arid zone had the highest coefficient of variation (30.16%) for the 30-year period annual rainfall followed by semi-humid (30.13%) and semi-arid (29.91%) zones while the transitional zone had the lowest (29.70%).

The distribution of the total annual rainfall for the 30-year period (1988–2018) in the four agro-ecological zones is shown in Figure 2. The total annual rainfall was highest in the semi-humid zone (968.82 mm), followed by the transitional zone (891.00 mm). Further the results indicated that the semi-arid zone had the second lowest mean (833.98 mm) for the total annual rainfall while the arid zone had the lowest (718.08 mm). Additionally, the results showed that the highest total annual rainfall in all the agro-ecological zones was recorded in 2006 while the lowest was recorded in 2005.

Table 1: Trend in 30-year period (1988-2018) annual rainfall in the study area

Agro-ecological Zone	Mean (mm)	Max (mm)	Min (mm)	S.D.	Coefficient of Variation	Mann-Kendall test		Sen's slope estimator
						Z-Stat	*P-Value*	
Arid	718.08	1282.75	347.92	216.60	30.16	-1.53	0.13	-6.59
Semi-arid	833.98	1563.97	457.62	249.48	29.91	-1.34	0.18	-4.59
Transitional	891.00	1593.79	513.21	264.60	29.70	-1.16	0.25	-3.96
Semi-humid	968.82	1756.99	554.58	291.24	30.13	-0.73	0.48	-3.99

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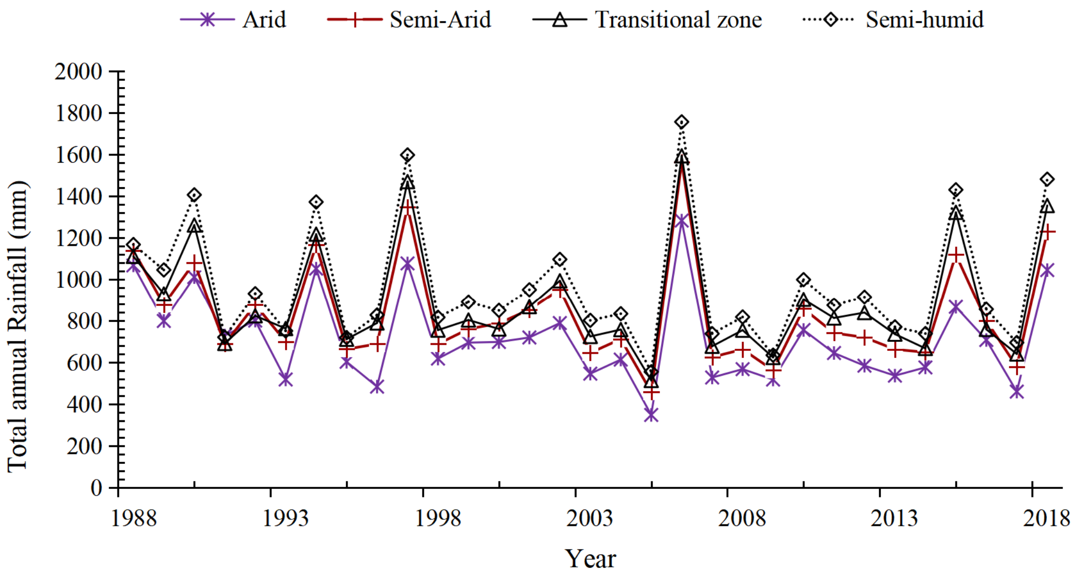

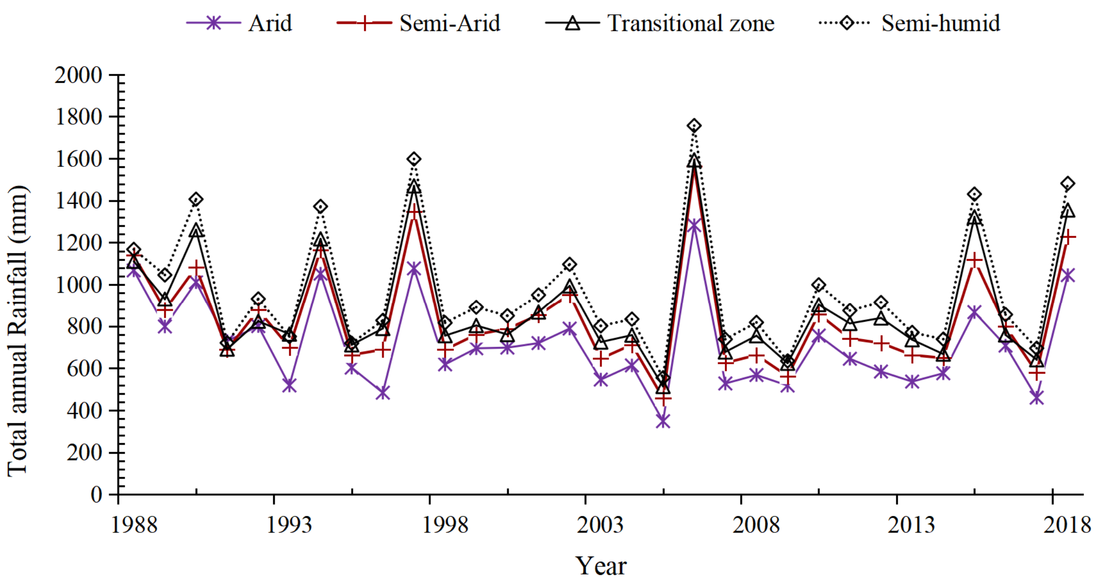

Figure 2: Total annual rainfall distribution for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

3.2 Seasonal rainfall trends and variability in the study area

3.2.1 March-April-May (MAM) seasonal rainfall trend and variability in the study area

Results from Mann-Kendall statistical test indicated a non-significant decreasing trend ($p<0.05$) in average rainfall for the March-April-May (MAM) season for a period of 30 years (1988-2018) in the arid and semi-arid zones. The Z-statistic values in the semi-humid and transitional zones were however positive indicating an increasing trend in MAM seasonal rainfall in the two zones as shown in Table 2. The results further indicated that the MAM rainfall decreased by 0.21 mm per year in the arid and semi-arid zones as shown by the Sen's slope estimator values while an increase of 0.09 mm and 0.52 mm per year was reported in the transitional and semi-humid zones, respectively. Additionally, the results revealed that the arid zone had the highest coefficient of variation (41.97%) for MAM seasonal rainfall for the 30-year period followed by semi-arid (41.69%) and semi-humid (41.29 %) zones while the transitional zone had the lowest (39.74%).

Table 2: Trend in 30-year period (1988-2018) average MAM seasonal rainfall in the study area

Agro-ecological Zone	Mean (mm)	Max (mm)	Min (mm)	S.D	Coefficient of Variation	Mann-Kendall test		Sen's slope estimator
						Z-Stat	P-Value	
Arid	232.02	593.94	88.46	97.39	41.97	-2.27	.79	-0.21
Semi-arid	289.89	724.00	113.97	120.84	41.69	-2.27	.79	-0.21
Transitional	348.36	835.49	165.25	138.45	39.73	0.14	.89	0.09
Semi-humid	377.23	930.74	167.91	155.77	41.29	0.38	.71	0.52

The MAM seasonal rainfall distribution for the 30-year period in the four agro-ecological zones is shown in Figure 3. The results showed that the MAM seasonal rainfall was highest in the semi-humid zone (377.23 mm), followed by the transitional zone (348.36 mm) while the semi-arid and arid zones had the second lowest (289.89 mm) and lowest (232.02 mm) means, respectively. The highest MAM seasonal rainfall in all the agro-ecological zones was recorded in 2018 while the lowest was recorded in 2009.

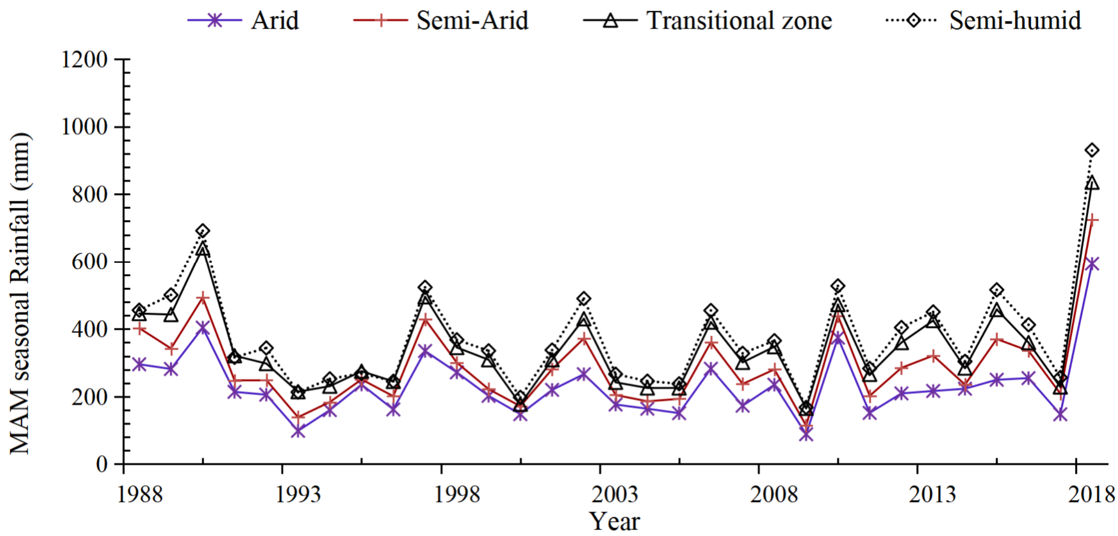

Figure 3: MAM seasonal rainfall distribution for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

3.2.2 October-November-December (OND) seasonal rainfall trend and variability in the study area

Regarding the October- November- December (OND) rainfall season, the Z-statistics values from Mann-Kendall statistical test were negative implying a decreasing trend in OND average rainfall in the four zones in the study area as shown in Table 3. The trend was however not statistically significant at 5% significant level. The Sen's slope estimator values showed that the arid zone had the highest amount of rainfall decrease per year (1.92 mm) followed by the semi-arid (1.78mm) and semi-humid (1.43mm) zones while the transitional zone had the lowest (1.19 mm). Additionally, the results indicated that the semi-humid zone had the highest coefficient of variation (44.70%) for OND rainfall for the 30-year period followed by transitional (43.25%) and semi-arid (42.56%) zones while the arid zone had the lowest (41.67%).

Table 3: 30-year period (1988-2018) trend in OND seasonal rainfall in the study area

Agro-ecological Zone	Mean (mm)	Max (mm)	Min (mm)	S.D	Coefficient of Variation	Mann-Kendall test		Sen's Slope Estimator
						Z-Stat	P-Value	
Arid	425.50	955.87	160.94	177.31	41.67	-1.84	.07	-1.92
Semi-arid	473.01	1145.03	194.52	201.32	42.56	-1.67	.09	-1.78
Transitional	474.84	1111.10	191.53	205.37	43.29	-1.29	.20	-1.19
Semi-humid	512.92	1222.33	200.04	229.25	44.69	-1.43	.15	-1.43

The OND seasonal rainfall distribution for the 30-year period in the four agro-ecological zones is shown in Figure 4. The OND seasonal rainfall was highest in the semi-humid zone (512.92 mm), followed by the transitional zone (473.01 mm). Further the results indicated that the semi-arid zone had the second lowest mean (473.03 mm) for OND seasonal rainfall while the arid zone had the lowest (425.50 mm). Additionally, the results showed that the highest OND seasonal rainfall in all the agro-ecological zones was recorded in 2006 while the lowest was recorded in 2005.

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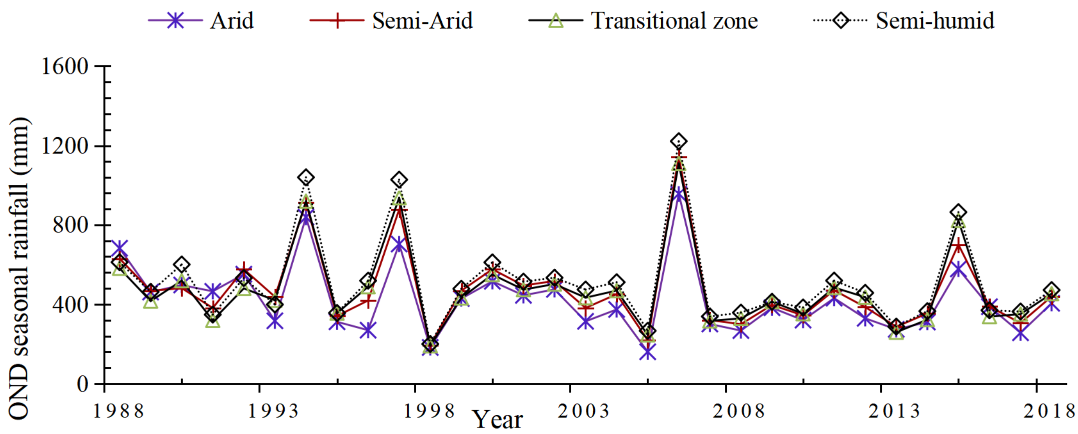

Figure 4: OND seasonal rainfall distribution for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

3.3 Temperature trends and variability in the study area

3.3.1 Annual temperature trends and variability in the study area

Mann-Kendall statistical test results for average annual maximum temperature for the 30-years period (1988-2018) indicated significant positive Z-statistics values implying that there was a statistically significant upward trend (p<.001) in average maximum temperature in all the four agro-ecological zones as shown in Table 4. Similarly, the results indicated that there was a statistically significant increasing trend in the average annual minimum temperature in all the four agro-ecological zones, at 5% significance level, as presented in Table 5. The Sen's slope estimator values showed that the average annual maximum temperature increased by 0.02^{o}C per year in all the four agro-ecological zones. In regard to the average annual minimum temperature, the Sen's slope estimator values showed a temperature increase of 0.02^{o}C per year in the semi-arid and transitional zones and 0.01^{o}C in the arid and semi-humid zones.

Table 4: Trend in 30-year period (1988-2018) average annual maximum temperature in the study area

Agro-ecological Zone	Mean (^{o}c)	Max (^{o}c)	Min (^{o}c)	S.D. (^{o}c)	Coefficient of Variation	Mann-Kendall test *Z-Stat*	*P-Value*	Sen's slope estimator
Arid	30.28	30.90	29.50	0.29	0.96	3.42	<.001	0.02
Semi-arid	30.28	30.90	27.30	0.29	0.96	3.56	<.001	0.02
Transitional	28.15	28.80	27.30	0.29	1.05	3.10	<.001	0.02
Semi-humid	30.28	30.90	29.50	0.29	0.96	3.32	<.001	0.02

Table 5: Trend in 30-year period (1988-2018) average annual minimum temperature in the study area

Agro-ecological Zone	Mean (^{o}c)	Max (^{o}c)	Min (^{o}c)	S.D. (^{o}c)	Coefficient of Variation	Mann-Kendall test *Z-Stat*	*P-Value*	Sen's slope estimator
Arid	18.36	18.85	17.87	0.27	1.47	2.05	0.04	0.01
Semi-arid	18.29	18.85	16.08	0.49	2.68	2.32	0.02	0.02
Transitional	16.22	16.72	15.60	0.28	1.74	2.30	0.02	0.02
Semi-humid	18.39	18.85	17.87	0.27	1.47	2.06	0.04	0.01

The results further revealed that the transitional zone had the highest coefficient of variation (1.05%) for average annual maximum temperature for the 30-year period followed by arid, semi-arid and semi-humid zones which had a similar coefficient of variation (0.96 %). With regard to average annual minimum temperature, the semi-arid zone had the highest coefficient of variation (2.68 %) followed by the transitional zone (1.74%) and lastly the arid and semi-humid zones which had a similar coefficient of variation (1.47%).

The annual mean maximum and minimum temperatures for the 30-year period in the four agro-ecological zones are shown in Figures 5 and 6, respectively. The highest mean annual maximum temperature (Tmax) was recorded in the arid, semi-arid and semi-humid zones (30.28°C) while the transitional zone had the lowest annual maximum temperature (28.15°C). Further, the results indicated that the highest annual maximum temperature in all the agro-ecological zones was recorded in 2003 and 2009 while the lowest was recorded in 1989.

In regard to annual minimum temperature (Tmin), the results showed that highest mean was recorded in semi-humid (18.39°C), followed by arid (18.36°C) and semi-arid (18.29°C) zones while the transitional zone had the lowest annual minimum temperature (16.22°C). Further, the results indicated that the highest annual minimum temperature in all the agro-ecological zones was recorded in 2010 while the lowest was recorded in 1989.

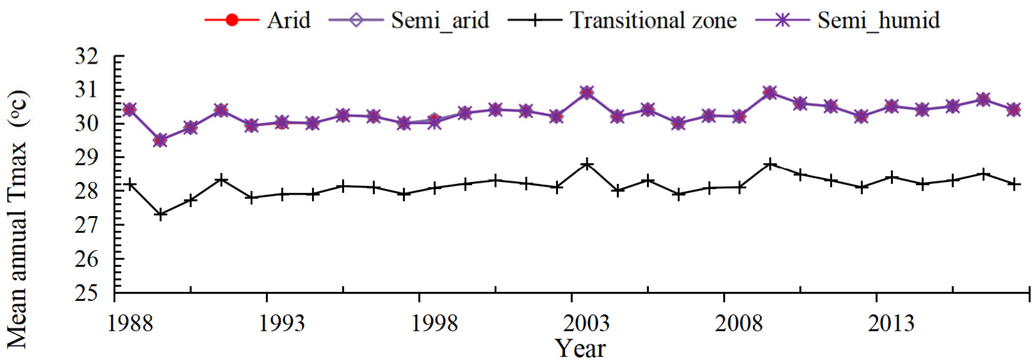

Figure 5: Mean annual maximum temperature for a 30-year period (1988–2018) in selected agro-ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

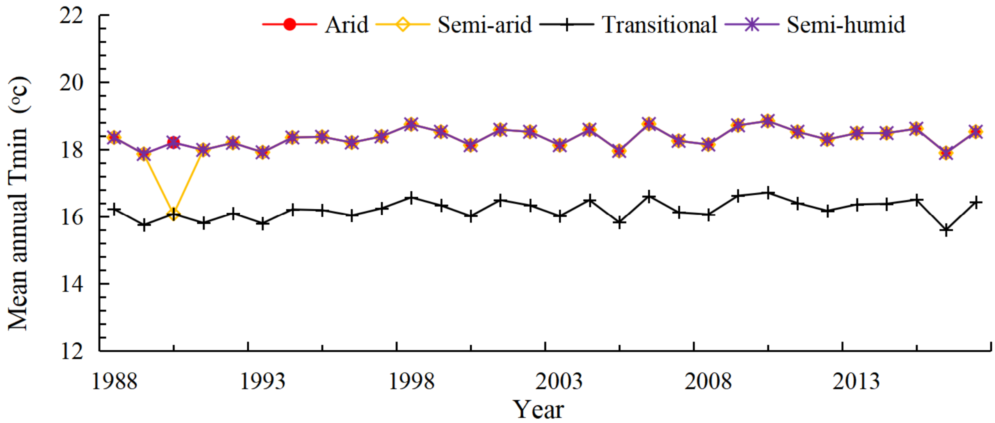

Figure 6: Mean annual minimum temperature for a 30-year period (1988–2018) in selected agro-ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

3.3.2 Annual mean temperature trends in the study area

Mann-Kendall statistical test results showed a significant increasing trend (*p*<.001) in a 30-years period (1988-2018) annual mean temperature in the four agro-ecological zones as shown in Table 6. Results from the Sen's slope estimator showed that the annual mean temperature increased by 0.02°C per year in all the four agro-ecological zones. Further scrutiny of the results revealed that the semi-humid zone had the highest coefficient of variation (2.40%) for average OND maximum temperature for the 30 years followed by arid and semi-arid zones with the same coefficient of variation (2.34%) and lastly the transitional zone (2.13%).

Table 6: Trend in 30-year period (1988-2018) annual mean temperature in the study area

Agro-ecological Zone	**Mean (°c)**	**Max (°c)**	**Min (°c)**	**S.D. (°c)**	**Coefficient of Variation**	**Mann-Kendall test**		**Sen's slope estimator**
						Z-Stat	***P-Value***	
Arid	24.34	24.94	23.64	0.27	1.10	3.98	<.001	0.02
Semi-arid	24.34	24.94	23.64	0.27	1.10	3.98	<.001	0.02
Transitional zone	22.18	22.80	21.10	0.33	1.47	3.88	<.001	0.02
Semi-humid	24.34	24.94	23.64	0.27	1.10	3.98	<.001	0.02

The annual mean temperature for the 30-year period in the different agro-ecological zones is presented in Figure 7. The highest mean temperature was recorded in the arid, semi-arid and semi-humid zones (24.34°C) while the transitional zone had the lowest mean temperature (22.18°C). Further, the results indicated that the highest mean annual temperature in all the agro-ecological zones was recorded in 2003 and 2009 while the lowest was recorded in 1989.

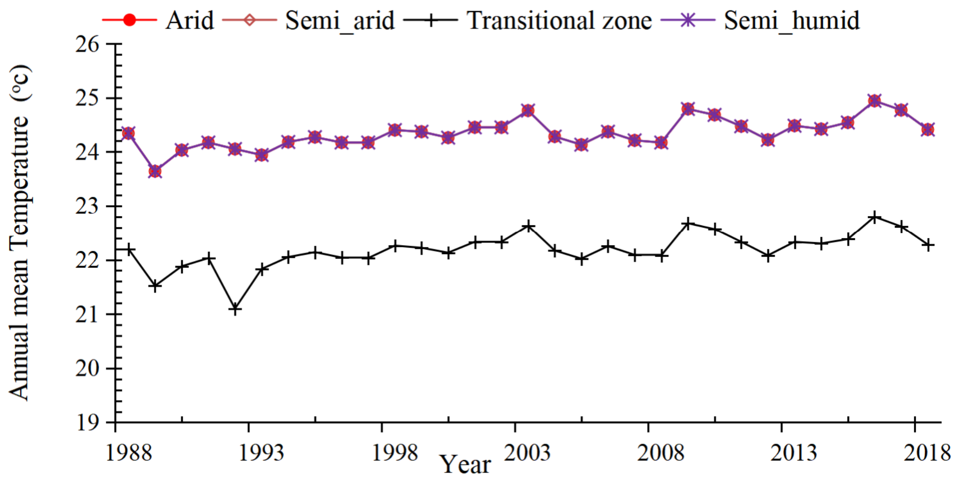

Figure 7: Average annual mean temperature for a 30-year period (1988–2018) in selected agro- ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

3.3.3 Seasonal temperature trends and variability in the study area

3.3.3.1 MAM seasonal maximum and minimum temperature trends and variability

Mann-Kendall statistical test results for average MAM maximum temperature for a period of 30 years (1988-2018) had positive Z-statistics values implying that there was an upward trend in average MAM maximum temperature in all the four agro-ecological zones as shown in Table 7. The trend was however not significant at 95% confidence level. Similarly, the results showed a non-significant increasing trend in average MAM minimum temperature at 95% confidence level in all the four agro-ecological zones as shown in Table 8. Further, the Sen's slope estimator values indicated that the MAM maximum and minimum temperatures increased by 0.01°C and 0.02°C per year respectively, in all the four agro-ecological zones.

Additionally, the results indicated that the transitional zone had the highest coefficient of variation (2.21%) for average MAM maximum temperature for the 30 years followed by arid, semi-arid and semi-humid zones which had a similar coefficient of variation (1.55%). Regarding average MAM minimum temperature, the transitional zone had the highest coefficient of variation (2.44 %) followed by the semi-humid zone (2.35%) and lastly, the arid and semi-humid zones which had a similar coefficient of variation (2.14%).

Table 7: Trend in 30-year period (1988-2018) average MAM maximum temperature in the study area

Agro-ecological Zone	Mean (°c)	Max (°c)	Min (°c)	S.D. (°c)	Coefficient of Variation	Mann-Kendall test		Sen's slope estimator
						Z-Stat	*P-Value*	
Arid	31.20	32.50	30.30	0.48	1.55	0.75	0.45	0.01
Semi-arid	31.20	32.50	30.30	0.48	1.55	0.75	0.45	0.01
Transitional	29.04	31.30	28.00	0.64	2.21	0.43	0.69	0.01
Semi-humid	31.20	32.50	30.30	0.48	1.55	0.75	0.45	0.01

Table 8: Trend in 30-year period (1988-2018) average MAM minimum temperature in the study area

Agro-ecological Zone	Mean (°c)	Max (°c)	Min (°c)	S.D. (°c)	Coefficient of Variation	Mann-Kendall test		Sen's slope estimator
						Z-Stat	*P-Value*	
Arid	19.51	20.40	18.60	0.42	2.14	1.48	0.14	0.02
Semi-arid	19.51	20.40	18.60	0.42	2.14	1.48	0.14	0.02
Transitional	17.49	18.40	16.57	0.43	2.44	1.43	0.15	0.02
Semi-humid	19.49	20.40	18.30	0.46	2.35	1.48	0.14	0.02

The MAM mean maximum and minimum temperatures for the 30-year period in the four agro-ecological zones are shown in Figures 8 and 9, respectively. The highest mean MAM maximum temperature (Tmax) was recorded in the arid, semi-arid and semi-humid zones (31.20°C) while the transitional zone had the lowest mean value (29.04°C). Further, the results indicated that the highest MAM maximum temperature in all the agro-ecological zones was recorded in 2003 while the lowest was recorded in 1989.

In regard MAM minimum temperature (Tmin), the results showed that the arid and semi-arid zones had the highest mean (19.51°C) followed by the semi-humid zone (19.49°C) while the transitional zone had the lowest MAM minimum temperature (17.49°C). Further, the results indicated that the highest MAM minimum temperature in all the agro-ecological zones was recorded in 2010 while the lowest was recorded in 1989.

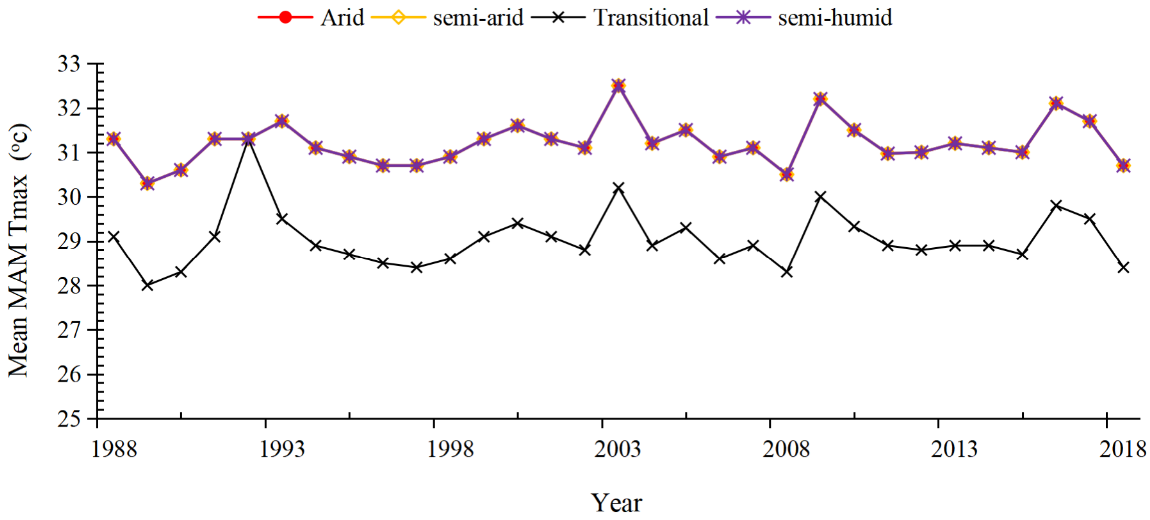

Figure 8: Mean MAM maximum temperature for a 30-year period (1988–2018) in selected agro-ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

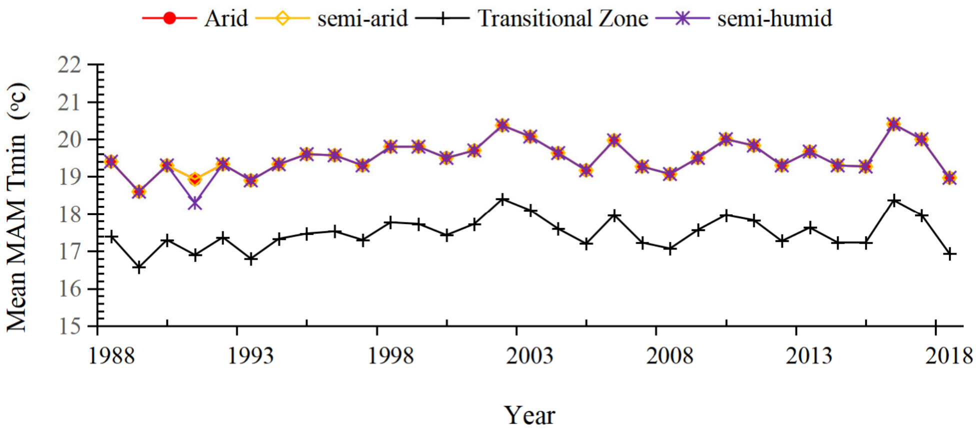

Figure 9: Mean MAM minimum temperature for a 30-year period (1988–2018) in selected agro-ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

3.3.2.2 OND seasonal maximum and minimum temperature trends and variability

Results from Mann-Kendall statistical test showed a significant increasing trend at 95% confidence level in the 30-years period (1988-2018) average OND maximum and minimum temperatures in the four zones as indicated in Tables 9 and 10, respectively. The Sen's slope estimator values indicated that the OND maximum and minimum temperatures increased by 0.03°C per year in all the four agro-ecological zones except in the transitional zone which reported an increase of 0.02°C for the OND maximum temperature.

In addition, the results indicated that the coefficient of variation for average OND maximum temperature for the 30-year period was highest in the semi-humid zone (2.40%) followed by arid and semi-arid zones with a similar coefficient of variation (2.34%) and lastly the transitional zone (2.13%). With regard to average OND minimum temperature, the transitional zone had the highest coefficient of variation (3.68 %), the semi-arid zone had the second highest (3.03%) while the arid and semi-humid zones had the lowest with a similar coefficient of variation (2.28%).

Table 9: Trend in 30-year period (1988-2018) average OND maximum temperature in the study area

Agro-ecological Zone	**Mean (mm)**	**Max (mm)**	**Min (mm)**	**S.D. (mm)**	**Coefficient of Variation**	**Mann-Kendall test**		**Sen's slope estimator**
						Z-Stat	***P-Value***	
Arid	30.18	31.10	29.10	0.59	2.34	2.34	0.02	0.03
Semi-arid	30.18	31.10	29.10	0.58	2.34	2.34	0.02	0.03
Transitional	28.13	29.00	27.10	0.55	2.13	2.13	0.03	0.02
Semi-humid	30.18	31.20	29.10	0.59	2.40	2.40	0.02	0.03

Table 10: Trend in 30-year period (1988-2018) average OND minimum temperature in the study area

Agro-ecological Zone	Mean (mm)	Max (mm)	Min (mm)	S.D. (mm)	Coefficient of Variation	Mann-Kendall test		Sen's slope estimator
						Z-Stat	*P-Value*	
Arid	18.74	19.73	18.03	0.43	2.28	3.49	0.00	0.03
Semi-arid	18.74	19.73	16.63	0.57	3.03	3.37	0.00	0.03
Transitional	16.85	18.73	18.07	0.62	3.68	3.11	0.00	0.03
Semi-humid	18.74	19.73	18.03	0.43	2.28	3.49	0.00	0.03

The OND mean maximum and minimum temperatures for the 30-year period in the four agro-ecological zones are presented in Figures 10 and 11, respectively. The highest mean OND maximum temperature (Tmax) was recorded in the arid, semi-arid and semi-humid zones (30.18°C) while the transitional zone had the lowest mean value (28.13°C). Further, the results indicated that the highest OND maximum temperature in all the agro-ecological zones was recorded in 2003 while the lowest was recorded in 1989.

In regard OND minimum temperature (Tmin), the results showed that the arid, semi-arid and semi-humid zones had the highest mean (18.74°C) while the transitional zone had the lowest OND minimum temperature (16.85°C). Further, the results indicated that the highest OND minimum temperature in all the agro-ecological zones was recorded in 2003 while the lowest was recorded in 1989.

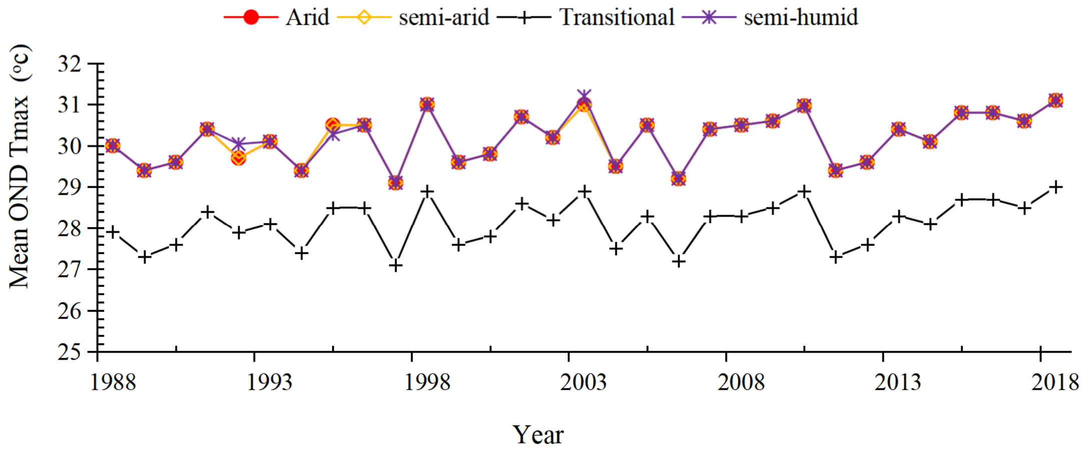

Figure 10: Mean OND maximum temperature for a 30-year period (1988–2018) in selected agro-ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

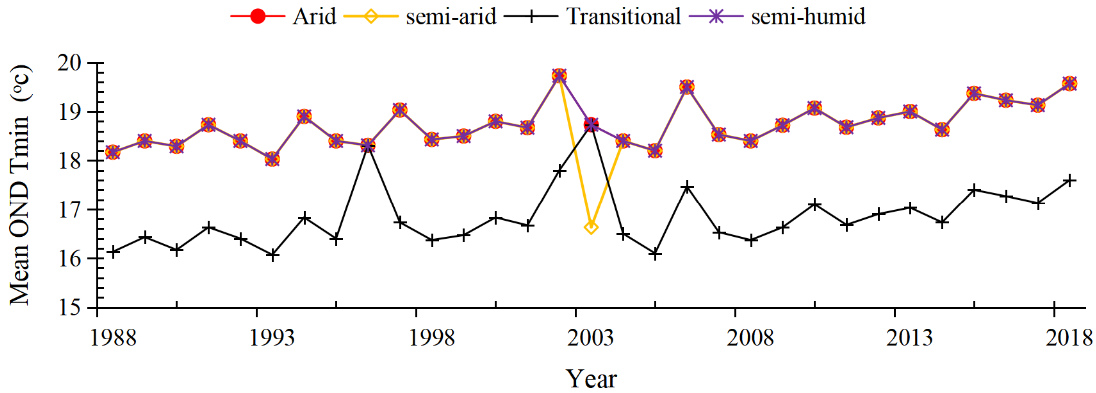

Figure 11: Mean OND minimum temperature for a 30-year period (1988–2018) in selected agro-ecological zones (Arid, Semi-arid, Transitional and Semi-arid) in Kitui County

4. DISCUSSION

4.1 Rainfall and temperature trends and variability in the study area

4.1.1 Rainfall trends and variability in the study area

The results established that there was an insignificant declining trend in annual rainfall in all the four agro-ecological zones in the study area. This could be attributed to the current changes in the climate system resulting from global warming. Significant warming trends have been reported in Eastern Africa and could be linked to the decreasing rainfall trend in the region (Christensen *et al.,* 2007; Niang *et al.,* 2014; Williams and Funk, 2010). The decreasing trend in rainfall in the study area could result to frequent occurrence of drought incidences causing a significant reduction in crop yields as well as pasture and water shortage for livestock production which are key sources of livelihood in the region. The findings are in consonance with results from a similar study by Aduma *et al.* (2018) which indicated a non-significant declining trend in annual rainfall in the Amboseli Ecosystem of Kenya. A similar trend in annual rainfall was also recorded along the Coastal Tanzania by Mahongo and Francis (2012). Additionally, the results of this study are in agreement with IPCC projections which indicated '*very likely'* reductions in annual rainfall in most parts of Africa with a general decrease in the 20th century being experienced in many arid and semi-arid regions in Africa (Collins *et al.*, 2013; Niang *et al.,* 2014).

Seasonal rainfall trends analysis results revealed a decreasing trend in the March-April-May (MAM) seasonal rainfall, which is also known as the "long rains" (Camberlin and Okoola, 2003) in the arid and semi-arid agro-ecological zones and an increasing trend in the transitional and semi-humid zones. The findings point out the spatial variation in the "long rains" which implies that while there has been a decreasing trend in the drier zones (the arid and semi-arid zones), an increasing trend has been reported in the wetter zones (transitional and semi-humid zones). The differential trends in the "long rains" could be due to the fact that a warming atmosphere is likely to cause higher evapotranspiration rates in wetter regions owing to their higher moisture content and vegetation resulting in more cloud formation and thus more precipitation in wetter zones compared to the drier zones (Christensen *et al.,* 2007; Collins *et al.,* 2013; Trenberth *et al.,* 2007). Conversely, increasing temperatures in drier regions are likely to cause additional drying of vegetation and water bodies leading to reduced evapotranspiration rates thus resulting in reduced precipitation in the drier zones (Dai *et al.,* 2004; Trenberth *et al.,* 2007). The results corroborate findings from similar research by Gebrechorkos *et al.* (2019) which showed that whereas there was a non-significant declining trend in MAM seasonal precipitation in the eastern regions of Kenya and Ethiopia, an insignificant upward trend in MAM seasonal precipitation was recorded in the western regions of both countries. Vondou *et al.*(2021) also reported both increasing and decreasing trends in rainfall patterns in different agro-ecological zones in Cameroon.

In regard to the October-November-December (OND) seasonal rainfall, also known as the "short rains" (Camberlin and Okoola, 2003), the results revealed a non-significant decreasing trend in the four agro-ecological zones implying a reduction in the amount of "short rains" with time. The decreasing trend in "short rains" could be due to the reduction in moisture in all the zones following a long dry period between the long and "short rains" coupled with increasing temperature resulting from global warming, consequently reducing evapotranspiration rates which in turn lead to reduced precipitation. The decreasing trend in the OND rainfall poses a threat to food security in the study area since it is considered the most reliable season for rain-fed agriculture in the region. The results of this study are concurrent with findings from Mutua and Runguma (2012) which indicated a significant increase in the OND seasonal rainfall in Nairobi and Embu since the 1970s. Similar studies by Gebrechorkos *et al.* (2019) and Opiyo *et al.* (2014b) have also noted an increasing trend OND seasonal rainfall in western parts of Kenya (Bungoma and Kisumu) and Turkana, respectively.

Additionally, the results indicated that there was high inter-annual and seasonal precipitation variability in all the agro-ecological zones as indicated by the coefficient of variation values. A coefficient of variation (CV) larger than 30% indicates high variability (Araya and Stroosnijder, 2011). Inter-annual and seasonal precipitation variability in East Africa has been attributed to El-Nino Southern Oscillation (ENSO) climate variability (Indeje *et al.*, 2000; Mutemi, 2003; Muthama *et al.,* 2014) as well as the increasing warming of the global climate (Schreck and Semazzi, 2004).

From the results, it was noted that the arid zone had the highest coefficient of variation for annual rainfall followed by the semi-humid and semi-arid zones while the transitional zone had the lowest. This finding implies that there is higher annual rainfall variability in the drier (arid) and wetter (semi-humid) zones compared to that in zones with intermediate climatic characteristics (semi-arid and transitional zones). The difference in rainfall variability in the zones could be because increasing temperatures are likely to result in large changes in the hydrological processes such as evapotranspiration and precipitation. Changes in these processes could extreme weather events with incidences of intense precipitation in the wetter zones and increased droughts incidences in the drier zones. On the other hand, rising temperatures are likely to have a moderate effect on the hydrological processes in the intermediate zones therefore resulting in less intense extreme weather events (Bates *et al.,* 2008; Dai *et al.,* 2004; Trenberth *et al.,* 2007). High rainfall variability is likely to cause incidences of weather anomalies such as droughts and floods which pose a significant threat to livelihoods in the study area due to their reliance on climate-sensitive natural resources. A similar finding of spatially different and high annual rainfall variability was reported by Tesfamariam *et al.* (2019) in different agro-ecologies in the rift valley lakes of Ethiopia. The results also corroborate findings from a similar study by Koskei *et al.* (2018) who reported high and varying annual rainfall variability in different agro-ecological zones in Baringo County, Kenya.

In regard to rainfall variability, the highest variability was reported in the arid zone followed by the semi-arid and semi-humid zones while the transitional zone had the lowest implying that MAM seasonal rainfall variability was higher in the arid, semi-arid and semi-humid zones compared to the transitional zone. The higher variability in arid and semi-arid zones could be probably due to the relatively higher temperatures in the arid and semi-arid lands compared to that in the wetter zones while the higher variability in semi-humid zone relative to the transitional zone could be attributed to higher moisture levels in the zone compared to those in the transitional zone.

Further, the results showed that the coefficient of variation for the OND seasonal rainfall was highest in the semi-humid zone followed by transitional and semi-arid zones while the arid zone had the lowest. The higher rainfall variability in the OND season in the semi-humid and transitional zones compared to the semi-arid and arid zones could be probably because of relatively higher moisture levels in the wetter zones compared to that in the drier zones resulting from the long dry period in between the long and "short rains". This causes more drying of water sources and vegetation in the arid and semi-arid zones compared to the wetter zones. The finding implies that location-specific analysis of rainfall variability should inform the design and execution of suitable adaptation measures for effective and successful climate variability response. The current study's results are consistent with findings by Ayanlade *et al.* (2018) which indicated a high and varying rainfall variability in growing seasons in the Rainforest and Guinea savanna agro-climatic zones in Nigeria. Similarly, Kisaka *et al.* (2015) reported high variability in both MAM and OND rainfall in different agro-ecological zones in Embu County, Eastern Kenya.

Further, the results indicated that the coefficient of variation for the OND seasonal precipitation was higher than that of MAM seasonal precipitation in all the agro-ecological zones except for the arid zone probably due to higher temperatures in the dry season between the long and short seasons since increasing temperatures are likely to cause high variability in rainfall patterns (Christensen *et al.,* 2007; Niang *et al., 2*014; Trenberth *et al.,* 2007). Additionally, around 50% of OND rainfall variability in Kenya could be attributed to the El Niño/Southern Oscillation (ENSO) which however has a very low influence on the MAM season (Muthama *et al.,* 2014). The higher rainfall variability in the OND seasonal rainfall compared to that in MAM seasonal rainfall in the research area could be a serious threat to food security since the OND seasonal rainfall is considered the main and most reliable season for crop production in the region. The results corroborate findings by Gummadi *et al.* (2020) which indicated an increasing variability in the OND seasonal rainfall in Embu County, Kenya.

4.1.2 Temperature trends and variability in the study area

Trend analysis results indicated a statistically significant upward trend in average annual maximum and minimum temperatures in all the four agro-ecological zones. A similar trend was recorded for OND seasonal average maximum and minimum temperatures in all the agro-ecological zones. An increasing but non-significant trend in average maximum and minimum temperatures for the MAM season was also recorded in all the agro-ecological zones. The rising temperature trend in the study area could be due to the current warming of the globe resulting from the rising GHGs concentration in the atmosphere where IPCC projections show that mean annual temperature rise is likely to surpass 2°C above the late 20th-century baseline in African regions in the middle of the 21st century and 4°C at the end of the 21st century (Niang *et al.,* 2014).

Coupled with decreasing rainfall trends, increasing temperatures are likely to cause increased and prolonged dry spells intensifying reduction in crop yields, scarcity of pasture and water shortage thereby threatening food security in the study area. The findings are in consonance with those from a study by Marigi *et al.* (2016) which showed a significant increasing temperature trend in South Eastern Kenya. Further, the current trend of results corroborates findings from similar studies (Asfaw *et al.,* 2017; Bobadoye *et al.*, 2014; Muhati *et al.*, 2018; Yvonne *et al.,* 2020).

In regard to temperature variability, the results established that there was low temperature variability in the study area (CV<30%) in all the agro-ecological zones compared to rainfall variability. This could be because according to Huntingford *et al.* (2013) changes in temperature means do not always imply a rise in temperature variability. Further, Pendergrass *et al.* (2017) noted that the magnitude of precipitation variability increases with change in mean precipitation as opposed to temperature variability which does not change systematically with warming. The current study's findings corroborate those from a similar study by Ngare *et al.* (2020) who reported low temperature variability as opposed to high rainfall variability in Kenya's Coastal region of Mombasa. Similarly, Kigomo *et al.* (2020) reported low inter-annual temperature variability in South West Mau Forest in Kenya.

5. Conclusion and Recommendations

The study established that there was a non-significant decreasing trend in annual rainfall in all the four agro-ecological zones in the study area. The decreasing annual rainfall which could be attributed to the current changes of the climate system resulting from global warming is likely to result in frequent occurrence of drought incidences causing a significant reduction in crop yields as well as pasture and water shortage for livestock production which are the main sources of livelihood in the study area.

In regard to seasonal rainfall trend analysis, the study established that there was a decreasing trend in March-April-May (MAM) seasonal rainfall in the arid and semi-arid agro-ecological zones and an increasing trend in the transitional and semi-humid zones.

Further, the study deduced that there was a non-significant decreasing trend in the October-November-December (OND) seasonal rainfall in the four agro-ecological zones. The decreasing trend in OND seasonal rainfall has a negative implication on food security since the OND seasonal rainfall is considered the most reliable season for rain-fed agriculture in the study area.

Additionally, there was a higher annual rainfall variability in the drier (arid) and wetter (semi-humid) zones compared to that in zones with intermediate climatic characteristics (semi-arid and transitional zones). This implies that the drier and wetter zones are likely to experience a higher occurrence of extreme weather events such as droughts, high-intensity rainfall and floods compared to the intermediate zones.

With reference to temperature, the study established that there was a statistically significant increasing trend in annual and OND seasonal average maximum and minimum temperatures was reported in all the four agro-ecological zones. The trend in average maximum and minimum temperatures for the MAM season in all the agro-ecological zones was however not significant. In regard to variability, the study established that there was low temperature variability in all the agro-ecological zones. Further, the study deduced that there was low-temperature variability compared to rainfall variability in all the four agro-ecological zones.

From the study, it can be recommended that households should be made aware of the variations in rainfall and temperature trends and encouraged to adopt climate smart agricultural technologies in order to reduce their sensitivity to the effects of climate variability. Further, the study recommends that adaptation planning should be guided by location-specific rainfall and temperature trends and variability for effective and successful implementation of adaptation strategies.

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Conflict of Interest

The authors declare no conflict of interest in the study.

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