MANN-KENDALL AND SEN'S SLOPE ESTIMATOR STATISTICAL TESTS FOR ANALYZING CHANGES IN METEOROLOGICAL VARIABLES IN KWALE COUNTY, KENYA

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ABSTRACT

Temperature and Precipitation variables were examined for 40 years in the four sub-counties of Kwale County in Kenya between 1980 and 2022. The statistical significance of the meteorological data was utilized to evaluate whether a positive or negative trend existed using the non-parametric Sen's and Mann-Kendall approaches. Annual temperature trends are positive and statistically significant for Kinango (Z_S=0.692 , Q_{med}=0.049, p<0.001); Lunga Lunga (Z_S=0.677 , Q_{med}=0.040, p<0.001); Msambweni (Z_S=0.610 , Q_{med}=0.042, p<0.001) and; Matuga (Z_S=0.641 , Q_{med}=0.043, p<0.001). However, the annual precipitation trends not statistically significant for Kinango (Z_S=0.026, Q_{med}=0.003, p>0.005); Lunga Lunga (Z_S=0.210 , Q_{med}=0.017, p>0.001); Msambweni (Z_S=-0.077, Q_{med}=-0.011, p>0.001) and; Matuga (Z_S=0.146, Q_{med}=0.011, p>0.001). Precipitation has not significantly changed in Kinango, Msambweni, Lunga Lunga, and Matuga. It is only in Lunga Lunga during June that precipitation changed significantly and in November for Lunga Lunga. Msambweni showed a slight positive change. In Matuga in november, there is a substantial positive upsurge in precipitation. From the study, climate change is occurring in Kwale County, Kenya.

Key Words: *climate change, precipitation trends, temperature trends, Sen's slope, Mann-Kendall*

Introduction

The high level of manufacturing and commercial activity that resulted in the release of greenhouse vapors such as methane, carbon dioxide, and others was what caused the industrial upheaval leading to climate variability in different parts of the world. Since 2000, GHG emissions have increased yearly by 3%, pushing the planet's ecosystem toward a high level of climate change that is both harmful and irreversible (Ambrosino et al., 2020). Large shifts in climate averages that last for epochs or more are denoted as climate change. Even though climate change is a worldwide phenomenon, its effects frequently differ from one place to another (Trajkovic and Kolakovic, 2009). Therefore, one crucial duty in the identification of climate change is the examination of vicissitudes in meteorological data. Numerous studies have been conducted recently to identify potential patterns and changes in the global climate. However, most of these studies have only looked at vicissitudes in maximum, minimum, or mean temperature, and precipitation (Woolf et al., 2010).

River Lancang in the years 1960 to 2000, at 19 stations was evaluated for climatic change patterns and characteristics by Yunling and Yiping (2005) according to archived data of monthly air temperature and precipitation series. They discovered rising temperatures and falling precipitation. Using the Mann-Kendall test and Sen's approach, Karaburun et al. (2011) from 1975 to 2006 examined the evolution of Istanbul's seasonal, annual, and monthly mean, minimum, and maximum temperatures. Elmer et al. (2010) studied temperature variations in the Kingdom of Saudi Arabia for 29 years using information from 29 meteorological stations. They established that there was a warming tendency in the annual maximum, minimum, and average temperatures, except for the winter months of November to January, when there was a negligible cooling trend. Using a 22 km gridded dataset, Ceppi et al. (2012) conducted a trend examination of temperature changes in Switzerland from 1959 to 2008. They discovered that the seasonal trends have an average yearly warming rate of 0.35 °C/decade, are all positive, and are largely significant.

Tao et al. (2011) have examined streamflow trends over the last 50 eons in River Tarim Basin. The findings showed that while there are positive changes in temperature, precipitation, relative humidity, and actual vapor pressure, there are negative trends in wind speed, sunshine length, and potential evapotranspiration. Xu et al. (2010) also had comparable outcomes. They concluded that over the previous 50 years, the mean annual air temperature and precipitation had both increased for the Tarim River Basin.

Singh et al. (2008) used the Mann-Kendall statistical test to evaluate the tendency and erraticism of seasonal and yearly rainfall as well as relative moistness on a basin scale for the northwest and central regions of India. According to their analysis, the relative humidity was on the rise both seasonally and annually in the majority of Indian river basins. Similar outcomes were obtained by Vincent et al. (2008) who examined trends in Canada's surface temperature and relative humidity from the years 1953 to 2005. In the years 1956 -2004 in china, based on an analysis of two observational datasets of wind speed changes, Jiang et al. (2010) concluded that all of them exhibit declining trends over significant portions of China.

According to several experts who examined the data on water haze (Philipona et al., 2005; Trenberth et al., 2005; Willett et al., 2007), there has been an upsurge in atmospheric water vapor. Numerous research (Modarres and Silva, 2007; Tabari and Hosseinzadeh Talaee, 2011a, 2011b; Tabari et al., 2011a) have looked at the variations in meteorological variables in Iran. Generally, their outcomes.

Method

Kwale is one of the six counties of Kenya's coastline area. It is situated along Kenya's southern coast, bordering Tanzania to the southwest. In addition, it shares borders with Kilifi, Mombasa, the Indian Ocean, and Taita Taveta to the north. The capital of Kwale County, Kwale, is located at 4.1816° S and 39.4606° E. It is distinguished by having a booming tourism business and offers sand beaches and coral reefs. Among the important topographic features that are present across the county are the coastal plain, Nyika Plateau, Coastal Uplands and the Foot Plateau. The area is semi-arid, which means that its soils are frequently thin and have a rocky system as its basement. Keeping livestock is the main activity.

The region's weather was hot and dry throughout the monsoon season, which lasts from January to April/May. The months of June through August each year are the coolest. These regions get bi-modal rainfall, with the short rains occurring from October to December and the long rains occurring from March to July (Rupa, Rejani & Bhat, 2013). The coastal lowlands experience temperatures ranging from 26.30 to 26.60 C, the Shimba Hills from 25 to 26.6 C, and the interior from 24.6 to 27.5 C. (KCDIP, 2013). According to the 2019 census, 866,820 people are living in the area overall, including 425,121 men and 441,681 women. The county was specifically chosen due to its distinctive climatic fluctuations and, more importantly, cashew nut growing in the area.

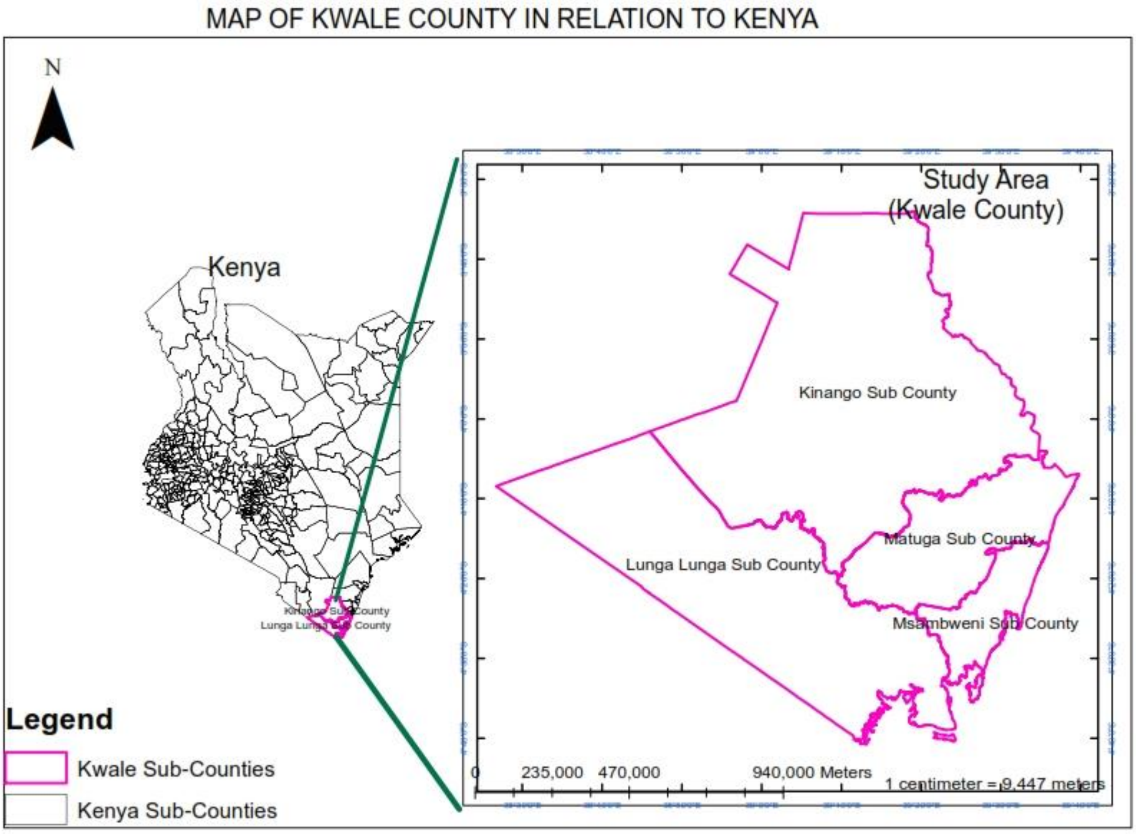


Figure 1 Map of Kwale County in relation to Kenya

Kenya Meteorological Department (KMD) and Kenya Agricultural Research and Livestock Organization (KARLO) Mtwapa provided the secondary data for the study. Publications from the Kenyan government, websites for Kwale County, theses, peer-reviewed journals, institutional websites, and textbooks were some of the other main sources of information. The study used climate data that were collected over 40 years (1981 - 2020). Average daily temperatures and precipitation for the 40 years covered by this study's analysis were acquired as secondary data. The Mann-Kendall test was used to analyze all of the indices, and trends were found in their time series. Based on the comparison of the observed number of discrepancies and the rank correlation statistic, a similar quantity's predicted value from a random series. The World Meteorological Organization has recommended the Mann-Kendall approach to evaluate the trend in environmental data time series. This test entails contrasting each time-series value with the remaining ones, always in sequential order. The number of instances where the remaining words exceed the analysis term is counted. According to Smadi, M. (2006), the statics for Mann-Kendall is given as:-

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} sign\ (x_i - x_j) \qquad (1)$$

Where *n* represents the data set length, x_j, and x_i and represent two general consecutive data values, and the (x_i-x_j) function sign adopts the succeeding values:

$$Sign\ (x_i - x_j) = \begin{cases} 1, & if\ (x_i - x_j) > 0, \\ 0, & if\ (x_i - x_j) = 0, \\ -1, & if\ (x_i - x_j) < 0. \end{cases} \qquad (2)$$

As a result, the S statistic is defined as the positive differences in the time series under analysis, less the negative differences. Under the null hypothesis, each collation of the data set is equally plausible because there is no trend in the data and no link between the variable under consideration and time. According to this theory, the statistic is circa normally dispersed with the mean E(S) and the variance Var (S) as follows:

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

$$Var\ (S) = \frac{1}{18}\left[n(n-1)(2n = 5) - \sum_{p=1}^{q} t_p(t_p - 1)(2t_p + 5)\right] \qquad (4)$$

where n is the times-series length, t_p is the quantity that ties for the pth value, and q is the quantity that ties, or equals values. The second term is an adjustment for data that has been tied or suppressed. The standardized test statistic Z is given by:

$$Z = \begin{cases} \frac{S-1}{\sqrt{Var\ (S)}} & if\ S > 0 \\ 0 & if\ \ S = 0, \\ \frac{S-1}{\sqrt{Var\ (S)}} & if\ \ S < 0. \end{cases} \quad (5)$$

The Z value is used to assess if a statistically significant trend exists. The null hypothesis, according to which there is no trend, is tested using this statistic. A positive Z represents an upward tendency in the time series, whereas a negative Z represents a downward trend. The null premise is vetoed if the utter value of Z is grander than Z(1-p/2), where Z(1-p/2) is derived from the conventional normal aggregate distribution tables, to test for either a growing or decreasing monotonic trend at the p significance level. For each of the time series that were evaluated in this study, the significant level p-value was calculated using the significance levels of 0.01, 0.05, and 0.1. Additionally, a non-parametric estimation of the slope's magnitude is

$$b = Median\left[\frac{X_j - X_i}{(j-i)}\right], for\ all\ i < j \quad (6)$$

Where is the incline amongst data points X_j and X_i measured at times *j* and *i*; correspondingly?

Results and Discussion

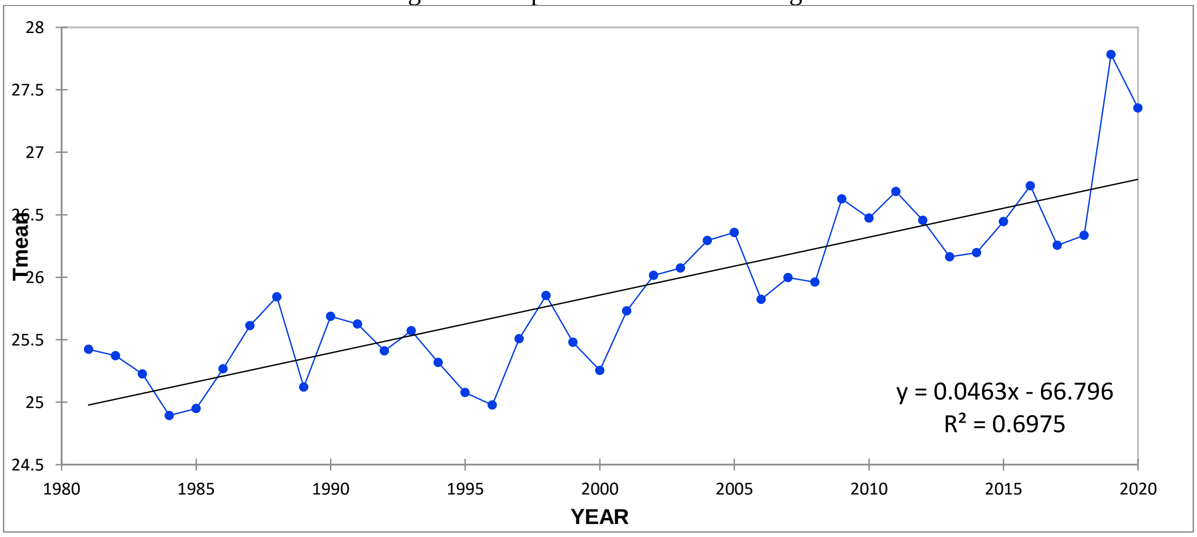
Temperature

Temperature is among the variables that were assessed in relation to climate change. There are four sub-counties in Kwale counties and temperature trends were observed for 40 years. In Matuga, the frostiest month is July with a mean average of 23.7400 C and the fieriest month is March with a mean average of 27.9860 C. As shown below:

Table 1 Temperature analysis for Matuga

Variable	Minimum	Maximum	Mean	Std. deviation
JAN	26.255	28.713	27.363	0.741
FEB	26.593	28.972	27.750	0.704
MAR	26.222	30.055	27.986	0.776
APR	25.758	29.497	26.916	0.665
MAY	24.180	26.896	25.474	0.691
JUN	23.296	26.409	24.439	0.673
JUL	22.407	25.713	23.740	0.759
AUG	22.355	30.251	23.916	1.265
SEP	23.185	25.746	24.352	0.679
OCT	24.151	27.559	25.342	0.803
NOV	24.927	28.003	26.209	0.724
DEC	25.835	28.686	27.078	0.734
ANNUAL	24.894	27.783	25.880	0.648

Figure 2 Temperature Trend for Matuga

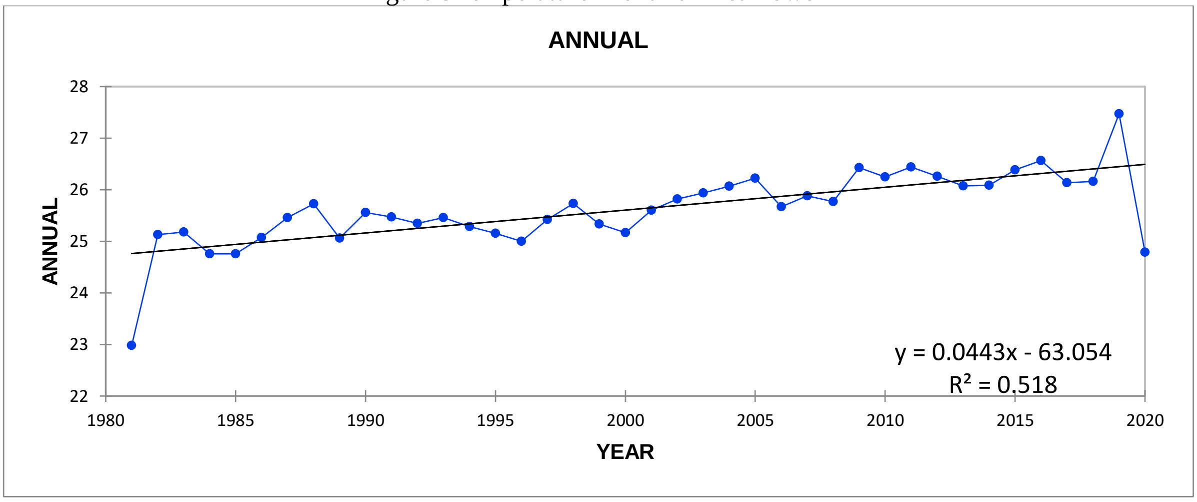


The slope (Figure 2) indicates positive values and therefore an indicator of an increasing trend. In Msambweni, the coldest month is July with a mean temperature of 23.593^{0}C. The hottest month is March with mean temperatures of 27.805^{0}C. As shown below:

Table 2 Temperature analysis for Msambweni

Variable	Minimum	Maximum	Mean	Std. deviation
JAN	0.000	28.573	26.654	4.379
FEB	26.556	28.834	27.691	0.650
MAR	26.051	29.909	27.805	0.754
APR	25.718	29.319	26.657	0.657
MAY	24.190	26.595	25.290	0.656
JUN	23.095	26.181	24.268	0.662
JUL	22.214	25.521	23.593	0.732
AUG	22.255	28.529	23.728	1.030
SEP	23.106	25.469	24.246	0.628
OCT	23.961	27.301	25.209	0.749
NOV	25.149	27.620	26.123	0.646
DEC	0.000	28.510	26.254	4.309
ANNUAL	22.981	27.472	25.627	0.720

Figure 3Temperature Trend for Msambweni

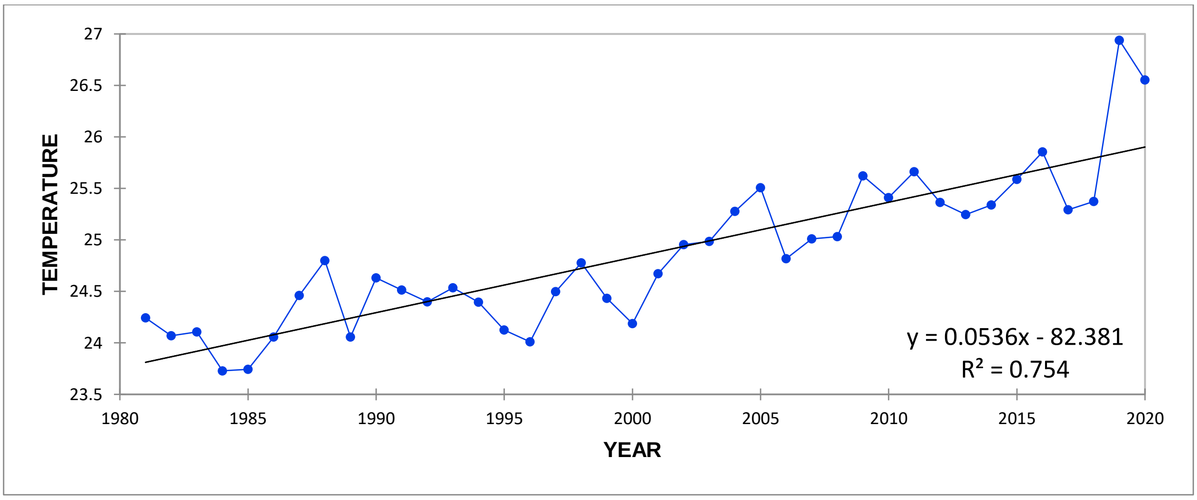


The slope (Figure 3) indicates a positive trend and therefore an increase in temperatures in the area from 1981 to 2020. In Kinango sub-county, July is the coldest month with mean temperatures of 22.637^{0}C. February is the fieriest month of the year with a mean temperature of 27.073^{0}C. As shown below;

Table 3 Temperature analysis for Kinango

Variable	Minimum	Maximum	Mean	Std. deviation
JAN	25.329	28.212	26.617	0.852
FEB	25.714	28.453	27.073	0.803
MAR	24.942	29.372	27.038	0.901
APR	24.559	28.817	25.621	0.765
MAY	23.017	26.271	24.254	0.785
JUN	21.945	25.742	23.222	0.793
JUL	21.009	25.043	22.637	0.898
AUG	21.078	28.115	22.797	1.148
SEP	22.044	24.883	23.391	0.776
OCT	22.934	26.796	24.320	0.887
NOV	24.032	27.152	25.213	0.769
DEC	24.856	27.881	26.096	0.778
ANNUAL	23.729	26.939	24.856	0.722

Figure 4 Temperature Trend for Kinango



From Figure 4, there has been a positive increase in temperatures in the area from 1981 to 2020.
In Lunga Lunga, July is the coldest month in Lunga Lunga sub-county associated with a mean temperature of 23.85 ^{O}C. March with a mean temperature of 20.049^{0}C is the hottest. As shown below:

Table 4 Temperature analysis for Lunga Lunga

Variable	Minimum	Maximum	Mean	Std. deviation
JAN	26.707	28.805	27.738	0.647
FEB	26.776	29.103	28.047	0.556
MAR	26.389	30.191	28.049	0.683
APR	25.877	29.385	26.884	0.655
MAY	24.399	26.486	25.542	0.626
JUN	23.274	26.026	24.517	0.654
JUL	22.457	25.429	23.857	0.684
AUG	22.562	27.142	23.997	0.798
SEP	23.488	25.745	24.609	0.573
OCT	24.230	27.203	25.569	0.670
NOV	25.547	27.554	26.533	0.554
DEC	26.171	28.769	27.316	0.673
ANNUAL	24.989	27.390	26.055	0.542

Figure 5 Lunga Lunga Temperature Trend

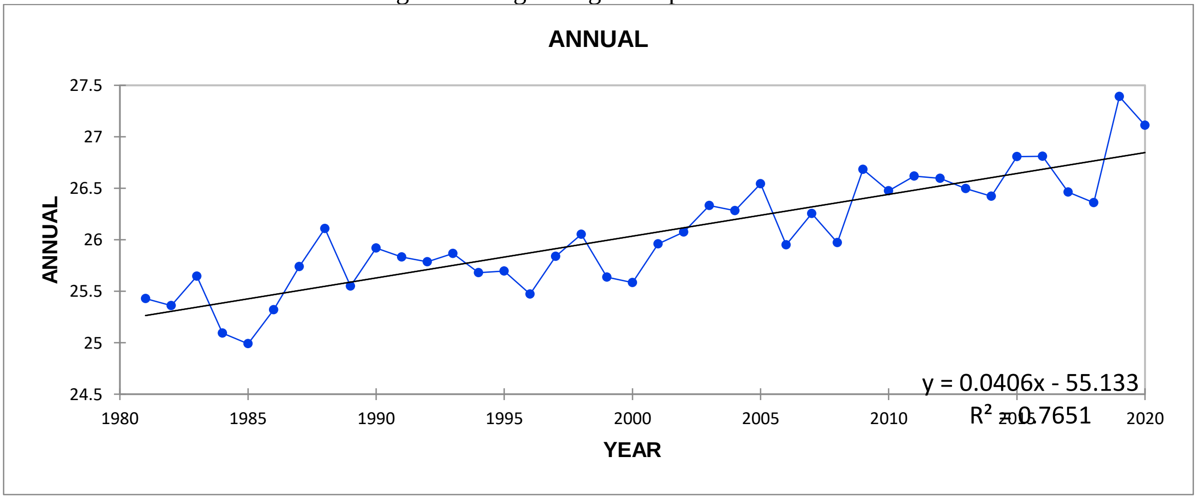


Figure 5 Shows positive values and therefore significant raise in temperatures from 1981 to 2020.

According to Table 5 below, the statistical tests for T_{mean} for for 40 years (1981-2020) are presented.
Table 5 Results of the statistical tests for monthly and annual Tmean over the period 1981–2020

	Kinango		Lunga Lunga		Msambweni		Matuga	
Trends	Q_{med}	Z_s	Q_{med}	Z_s	Q_{med}	Z_s	Q_{med}	Z_s
January	0.556**	0.056**	0.559**	0.045**	0.590**	0.051**	0.528**	0.047**
February	0.513**	0.051**	0.495**	0.032**	0.503**	0.042**	0.490**	0.044**
March	0.551**	0.057**	0.541**	0.038**	0.544**	0.045**	0.523**	0.046**
April	0.423**	0.031**	0.367**	0.024**	0.377**	0.027**	0.403**	0.027**
May	0.410**	0.041**	0.377**	0.032**	0.392**	0.034**	0.418**	0.036**
June	0.562**	0.042**	0.556**	0.045**	0.562**	0.04**	0.523*	0.038*
July	0.613**	0.058**	0.621**	0.047**	0.628**	0.047**	0.595**	0.047**
August	0.610**	0.059**	0.679**	0.050**	0.608**	0.052**	0.566**	0.054
September	0.621**	0.055**	0.674**	0.042**	0.608**	0.044**	0.579**	0.045**
October	0.628**	0.058**	0.600**	0.045**	0.608**	0.048**	0.579	0.052
November	0.610**	0.053**	0.615**	0.039**	0.592**	0.045**	0.572**	0.046**
December	0.646**	0.054**	0.590**	0.046**	0.531**	0.044**	0.613**	0.049**
Annual	0.692**	0.049**	0.677**	0.040**	0.610**	0.042**	0.641**	0.043**

Z_S: Mann-Kendall test, Q_{med}: Sen's slope estimator.
* *Statistically significant trends at the 5% significance level.*
** *Statistically significant trends at the 1% significance level*

All the significant trends as shown at 1% and 5% levels of significance were increasing. Annually, the trends were detected to have snowballing trends at a 1% significance level in all the four sub-counties of Kwale and varied between 0.692^{0}c annually for Kinango, and 0.677^{0}c for Lung Lunga, 0.610^{0}c for Msambweni, and 0.641^{0}c for Matuga (Table 5). On a monthly basis, positive significance trends were detected in Matuga, Kinango, Lunga Lunga and Msambweni. The air temperature increasing trends have been caused by numerous dynamics such as vicissitudes in atmospheric circulation, amplified urbanized areas, and global warming (Smadi, 2006; Tabari et al., 2011a).

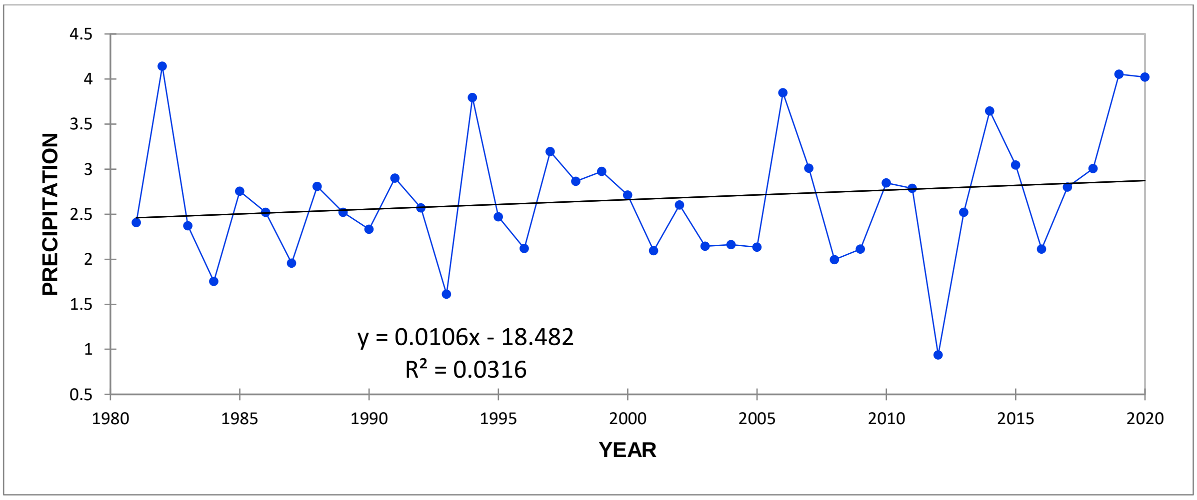
Precipitation

The mean precipitation for the four sub-counties over the past 40 years was also computed. In Matuga sub-county the highest amount of precipitation occurs during May while the least amount of precipitation occurs in February (**Error! Reference source not found.**).

Table 6 Precipitation analysis for Matuga Sub County

Variable	Minimum	Maximum	Mean	Std. deviation
JAN	0.000	4.485	0.594	0.930
FEB	0.000	2.336	0.179	0.452
MAR	0.000	5.754	1.491	1.384
APR	0.432	11.337	4.681	2.795
MAY	1.974	16.487	7.906	3.871
JUN	0.027	6.563	2.728	1.578
JUL	0.249	6.394	2.231	1.307
AUG	0.120	5.342	1.761	1.155
SEP	0.048	5.521	2.012	1.508
OCT	0.120	13.776	3.079	3.015
NOV	0.492	9.232	3.725	2.360
DEC	0.011	6.432	1.608	1.510
ANNUAL	0.937	4.142	2.666	0.695

Figure 6 Matuga Sub-County Precipitation Trend



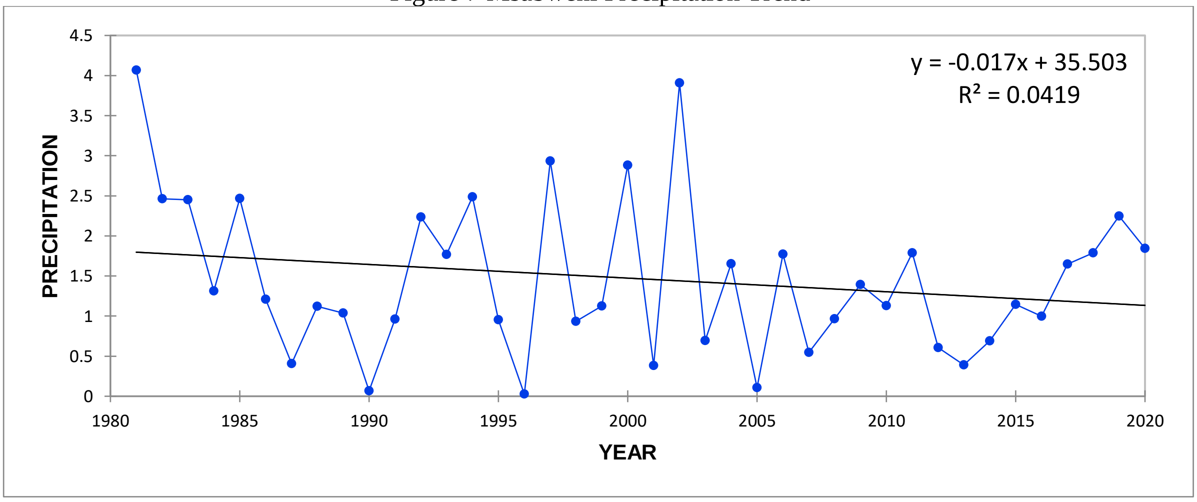
There is a slight increase in the amount of rainfall experienced in the Matuga Sub-county from 1981 to 2020 according to **Error! Reference source not found.**

Table 7 Msambweni Sub-County Precipitation analysis

Variable	Minimum	Maximum	Mean	Std. deviation
JAN	0.000	2.746	0.538	0.692
FEB	0.000	2.658	0.285	0.492
MAR	0.014	6.902	2.032	1.710
APR	1.335	18.956	6.841	3.411
MAY	0.906	25.103	10.714	6.094
JUN	0.944	8.076	3.969	2.150
JUL	0.444	6.377	3.132	1.586
AUG	0.004	5.749	1.869	1.451
SEP	0.158	5.531	1.835	1.371
OCT	0.384	14.650	3.285	2.975
NOV	0.132	14.704	3.596	2.757
DEC	0.026	4.069	1.465	0.971
ANNUAL	0.026	4.069	1.465	0.971

According to Table 7, Msambweni experiences the highest precipitation in May with a mean rainfall of 2,032mm while the lowest was in February.

Figure 7 Msabweni Precipitation Trend



The slope shows a reducing figure therefore a declining amount of precipitation in Msambweni (Figure 7).

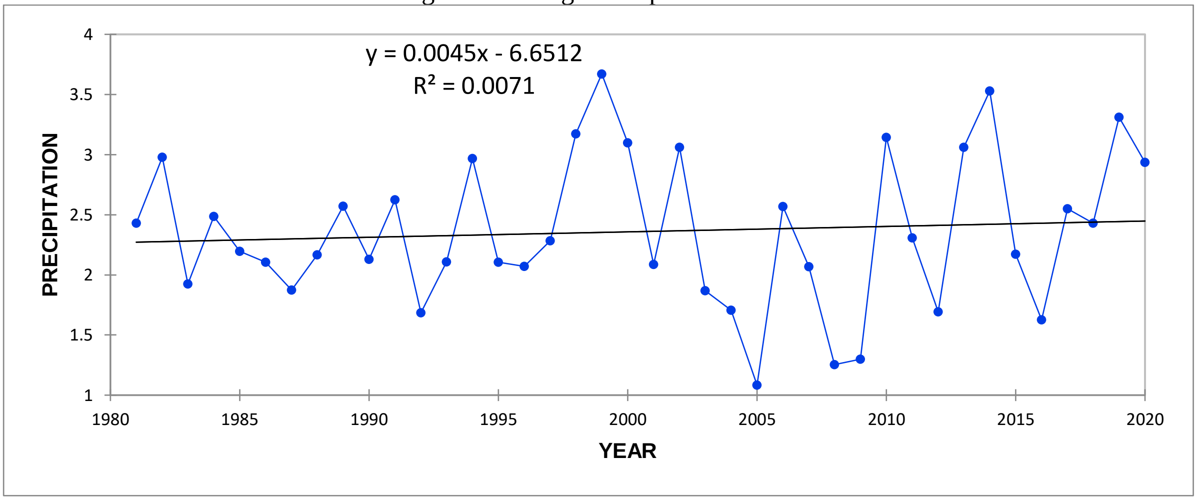
Table 8 Kinango Sub-County Precipitation analysis

Variable	Minimum	Maximum	Mean	Std. deviation
JAN	0.000	5.460	0.929	1.134
FEB	0.001	5.033	0.583	0.973
MAR	0.064	6.613	1.786	1.644
APR	0.394	10.728	3.598	2.282
MAY	0.546	13.262	6.376	3.523
JUN	0.060	6.464	2.382	1.555
JUL	0.372	4.211	1.829	0.998
AUG	0.004	4.127	1.476	1.074

SEP	0.006	6.444	1.377	1.386
OCT	0.309	11.301	3.006	2.485
NOV	0.222	8.541	3.048	1.730
DEC	0.000	4.778	1.930	1.337
ANNUAL	1.084	3.671	2.360	0.624

The month of May with a mean Precipitation of 6.366mm in Kinango experiences the highest precipitation while the lowest is experienced in February according to Table 8

Figure 8 Kinango Precipitation Trend



There is a slight increase in levels of precipitation in Kinango from 1981 to 2020 according to

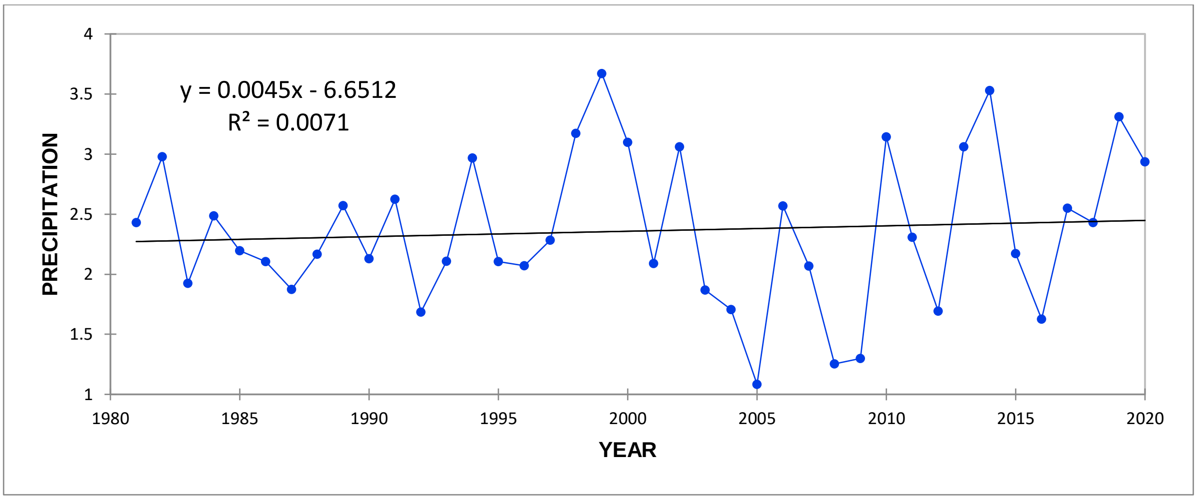
Figure 8

Table 9 Lunga Lunga Precipitation Analysis

Variable	Minimum	Maximum	Mean	Std. deviation
JAN	0.001	6.905	1.117	1.363
FEB	0.000	3.665	0.657	0.776
MAR	0.057	4.776	1.675	1.114
APR	1.755	12.991	4.460	2.298
MAY	1.294	15.344	6.595	3.289
JUN	0.130	8.597	3.268	2.352
JUL	0.226	3.550	1.971	0.818
AUG	0.199	6.186	1.905	1.105
SEP	0.215	7.045	1.856	1.426
OCT	0.175	13.243	3.068	2.601
NOV	0.818	10.204	4.197	1.939
DEC	0.761	10.637	3.430	2.086
ANNUAL	1.861	4.281	2.850	0.671

Lunga Lunga experiences the highest precipitation in May with a mean of 1.675mm and the least precipitation in February according to Table 9

Figure 9 Lunga Lunga Precipitation Trend



The trend shows positive values, therefore, a slight increase in precipitation in the area from 1981 to 2020, Figure 9

Table 10 Results of the statistical tests for monthly and annual precipitation over the period 1981–2020

	Kinango		Lunga Lunga		Msambweni		Matuga	
Trends	Q_{med}	Z_s	Q_{med}	Z_s	Q_{med}	Z_s	Q_{med}	Z_s
January	-0.077	-0.001	0.064	0.005	0.000	0.000	0.008	0.000
February	-0.035	-0.000	0.203	0.011	0.123	0.000	0.071	0.000
March	-0.008	-0.000	0.128	0.017	0.069	0.010	0.041	0.006
April	-0.049	-0.012	-0.038	-0.015	-0.064	-0.033	-0.187	-0.08
May	0.031	0.014	0.051	0.021	0.159	0.127	0.087	0.035
June	0.041	0.009	0.364**	0.109**	-0.179	-0.064	0.041	0.007
July	-0.213	-0.023	-0.041	-0.004	0.008	0.002	-0.090	-0.015
August	-0.205	-0.024	-0.023	-0.003	-0.005	-0.002	0.044	0.006
September	0.064	0.008	0.208	0.023	0.113	0.020	0.110	0.019
October	0.172	0.032	0.077	0.014	0.128	0.027	0.133	0.038
November	0.185	0.042	0.259*	0.061*	0.318*	0.089*	0.272**	0.078**
December	-0.041	-0.007	-0.151	-0.031	-0.077	-0.011	-0.033	-0.006
Annual	0.026	0.003	0.210	0.017	-0.077	-0.011	0.146	0.011

Z_S: Mann-Kendall test, Q_{med}: Sen's slope estimator.
* *Statistically significant trends at the 5% significance level.*
** *Statistically significant trends at the 1% significance level.*
According to

Table 10**Error! Reference source not found.**, precipitation has not significantly changed in Kinango, Msambweni, Lunga Lunga, and Matuga. It is only in Lunga Lunga during June that precipitation changed significantly. In November in Lunga Lunga, Msabweni showed a slight positive change. In Matuga, there is a significant positive increase in precipitation in November.

Conclusion

Based on mean air temperatures and precipitation, this study examined the climatic variability occurring in Kwale County on a monthly, seasonal, and annual basis. A warming tendency for the annual series is revealed by an analysis of Mean temperatures. Precipitation has not significantly changed. Climate in Kwale County Kenya is changing significantly as this can be highlighted by the drastic changes in temperature.

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