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Investigation of Rainfall Variability over Kenya (1950-2012)

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Abstract: This study investigates the rainfall variability from 33 stations, for a period of 63 years (1950 – 2012) over Kenya. Coefficient of Variability and non-parametric Mann-Kendall test at 5% level of significance was used to assess the variability and trend, respectively. The Sen's slope estimator was then used to find the magnitude of the changeover the time period. It was observed that October to December season had a high inter-annual variability, with most stations having greater than 50% of the Coefficient of Variation compared to March to May season, which had only 4 stations with over 50% Coefficient of Variation. Insignificant decreasing trend was noted during the March – May rains, while insignificant increasing trend in October – December rains. On a spatial scale, a negative trend was noted in the northern part of the country and the opposite condition was noted in western regions of the country, around Lake Victoria area. The results indicate a likelihood of negative impact on sectors of the economy that relay on rainfall, because of negative trend in March – May long rains, which accounts for most of rains received annually in Kenya. Although the October – December rains have an increasing trend, they are unreliable due to high inter-annual variability.

Keywords: Rainfall; climate change; Trend analysis; Mann-Kendall; Coefficient of Variation.

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1. Introduction

Rainfall is highly variable over East Africa at spatial as well as temporal scale (Indeje et al., 2001). On temporal scale, the variability is attributed to a number of factors among them: Indian Ocean Dipole, El Nino Southern Oscillation, anticyclones, jet streams, Madden-Julian Oscillating (Owiti et al., 2008; Black et al., 2003; Ogwang et al., 2015; Berhane and Zaitchik, 2014; Hogan et al., 2015). However, spatial variability is attributed to the orography and abundance of water bodies (Ongoma et al., 2015; Nyakwada, 2009). Due to this high variability and anomalies in rainfall, trend analysis has been of great interest to researchers in the region (Amin et al., 2018; Darand et al., 2017; Funk et al., 2014; IPCC 2014; Li et al., 2018; Sun et al., 2018; Yang et al., 2014).

Climate change induced irregularities in amount and frequency of extreme precipitation events are likely to increase across the globe (IPCC, 2007; Forsythe et al., 2017; He et al., 2017; Knapp et al., 2017; Siam and Eltahir, 2017; Zhang, 2018). Recent extreme events in Kenya including the droughts of 2011 and 2014, although these were spatially localized, however, attributed to climate change (Ongoma et al., 2015; Marthews et al., 2015). Projected increasing global warming is likely to significantly increase seasonal variability in precipitation over East Africa. By 2050 increasing precipitation trend is predicted during October to December (OND), while decreasing trend for March to May (MAM) (Hulme et al., 2001). These spatiotemporal variations will have serious implications leading to future water vulnerabilities for water security at regional as well as global scales (Vorosmarty et al., 2000; Milly et al., 2005; Eakin and Luers. 2006; Ben-Mohamed, 2010; Ahmed et al., 2014; Forsythe et al., 2017; Gao et al., 2017; Xia et al., 2017; Zhang et al., 2017).

In Kenya climate change is costing huge socio-economic losses (Awuor et al., 2008; Kabubo-Mariara and Karanja, 2007; Mati, 2000; Muthoni et al., 2017; Ochieng et al., 2016). According to Niang et al. (2014), the African continent has warmed by 0.5 °C and the annual temperatures are projected to rise by 3 to 4 °C by the end of 21st century. This is likely to negatively impact on rainfall and consequently affect the development of many African countries including Kenya. Approximately 60% of Kenya's economy is dependent on rain fed agriculture (Ongoma et al., 2013; Funk et al., 2008; Ngetich et al., 2014). Therefore, understanding of spatiotemporal anomalies in rainfall is mandatory in order to device effective adaptation measures to the changing climate and ensure food and water security (Haile, 2005; Funk et al., 2008; Lobell et al., 2008; Battisti and Naylor. 2009; Challinor et al., 2014; Rehmani et al., 2014; Conway et al., 2015).

Analyzing the rainfall variability fundamental in climate change detection and attribution studies (Meehl et al., 2000). In recent times, several studies on rainfall trends and variability have been carried out at different spatial scales. Studies across East Africa region reveal that there has been high rainfall variability within the region (Hulmeet al., 2001; Shisanya et al., 2011; Moyo et al., 2012;Wagesho et al., 2013; Ngaina and Mutai, 2013; Ongoma et al., 2015; Nicholson, 2016).

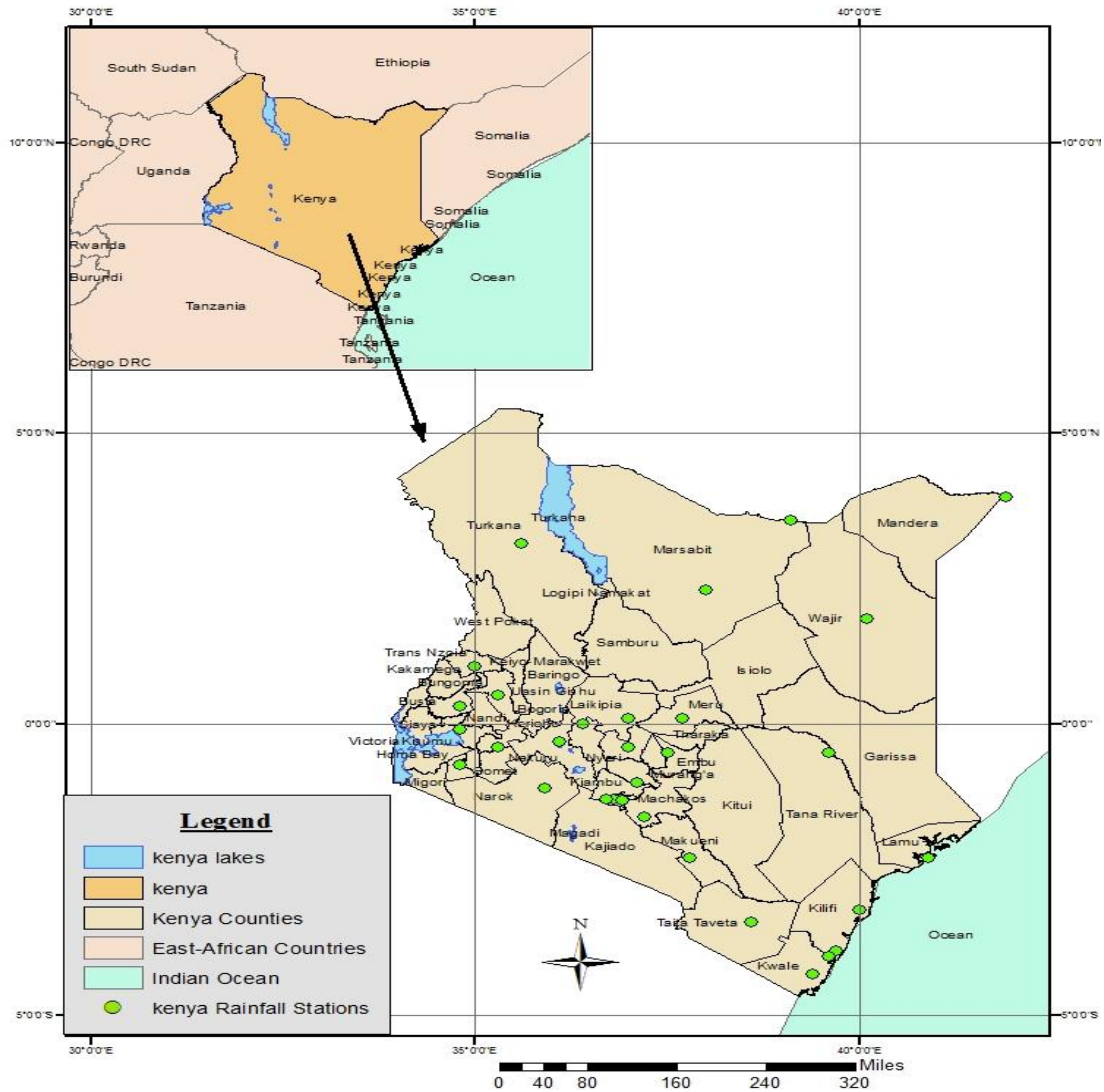

Fig. 1. Map of study area showing the position of Kenya and the spatial distribution of rainfall observing stations used in the study.

In Kenya, recent study by Opiyo et al. (2014) focused on rainfall and temperature trends and variability in Turkana County, north western parts of Kenya. As per their findings, MAM rainfall has a decreasing trend while OND had an increasing trend. In a different study, Wakachala et al. (2015) looked into rainfall variability in the Great Rift Valley of Kenya and observed a high variability of rainfall over the semi-arid region of Rift Valley and a decreasing rainfall trend during the MAM season.

This study aims to investigate seasonal and annual rainfall variability over Kenya by using observed station rainfall data, for over 63 years (1950-2012) through non-parametric statistical technique. The findings of this study are intended to provide information on the long term rainfall trend which could indicate the magnitude of climate variability and change at local level. Obtained information will potentially help in formulation of mitigating and adaptation strategies for various spheres of society that are likely to be vulnerable to changing climatic conditions (Preston et al., 2011).

Table 1. List of rainfall datasets

Station	Latitude	Longitude	Elevation (m)	Data length
Lodwer	35.6	3.1	505	1950-2012
Kericho	35.3	-0.4	1976	1974-2012
Machakos	37.2	-1.6	1600	1957-2012
Kisumu	34.8	-0.1	1149	1959-2012
Kisii	34.8	-0.7	1771	1963--2012
Voi	38.6	-3.4	558	1950-2012
Makindu	37.8	-2.3	1000	1950-2012
Marsabit	38	2.3	1345	1950-2012
Narok	35.9	-1.1	1585	1950-2012
Kakamega	34.8	0.3	1582	1958-2012
Thika	37.1	-1	1463	1957-2012
Mtwapa	39.7	-3.9	21	1959-2012
Mombasa	39.6	-4	5	1957-2012
Embu	37.5	-0.5	1494	1976-2012
Nyeri	37	-0.4	1798	1968-2012
Dagoretti	36.8	-1.3	1798	1955-2012
Meru	37.7	0.1	1524	1966-2012
Kitale	35	1	1840	1979-2012
Nakuru	36.1	-0.3	1836	1964-2012
Nyahururu	36.4	0	2392	1961-2012
Wajir	40.1	1.8	244	1950-2012
Moyale	39.1	3.5	1110	1950-2012
Malindi	40	-3.2	20	1961-2012
Eldoret A.	35.3	0.5	2079	1972-2012
Mandera	41.87	3.9	330	1957-2012
Garissa	39.6	-0.5	128	1959-2012
Lamu	40.9	-2.3	6	1950-2012
Msabaha	39.4	-4.3	91	1957-2012
M.A.B	36.9	-1.3	1637	1967-2012
Wilson	36.8	-1.3	1679	1957-2012
JKIA	36.92	-1.32	1624	1958-2012
Nanyuki	37.03	0.05	1890	1957-2012
Naivasha	36.38	-0.7	1899	1961-2012

2. Data and Methodology

2.1. Study Area

The area of study is Kenya and is located between longitudes 34°E to 42°E, and latitudes 5°N to 5°S (Fig. 1), with a total area of about 582650 km^2. Kenya has a varied topography; the highest point in the area is Mount Kenya (5199 m above seas level), while the coastal area is near mean sea level. The regional inland lake system includes Lake Victoria (68,400 km^2), which is a source of moisture and energy (Indeje, 2001). The Indian Ocean lies to the south east boundary of the country. These features significantly influence the local circulation pattern and hence affect the spatial and temporal rainfall variability in Kenya (Asnani and Kinuthia, 1979).

Kenya experiences bimodal rainfall regime with the 'long rains' season coming MAM and the 'short rains' being reported in OND (Yang et al., 2015; Camberlin and Philippon, 2002; Mutai and Ward, 2000; Ogwang et al., 2015). These rainy seasons coincide with periods of the year when the Inter-Tropical Convergence Zone (ITCZ) is overhead at the equator (Anyah and Semazzi., 2006). The intervening periods are relatively dry. However, there are rainfall-enhancing mechanisms in the region, which contribute to substantial rains over the western and coastal parts of East Africa in June-August (JJA). These mechanisms include the migration of warm and moist Congo air mass, and the East Africa low level jet (EALLJ), respectively (Farmer, 1988; Anyamba and Kiangi, 1985; Davies and Vincent, 1985; Ininda, 1995).

2.2. Data

Monthly rainfall data was collected from Kenya Meteorological Department (KMD). The stations were selected based on completeness and quality of data set and spatial distribution over the county. It had different length, ranging from 1950 to 2012 (Table 1). While the monthly gridded data was sourced from Climate Research Unit (CRU), spanning from 1901 to 2010, it is gauge-based, gridded at 0.5° by 0.5° resolution. The data is discussed in detail by Harris et al. (2014). Ongoma and Chen, (2017) validated the CRU and GPCC data against the observed data over Kenya, as per their findings, the CRU data replicate the observed data with a high correlation coefficient of 0.97, the same results were also obtained by Ogwang et al. (2015).

2.3. Methodology

Coefficient of variation (CV) was used to assess the variability of seasonal and annual rainfall data for all the 33 stations. Comparative values of CV among different stations were also conducted to determine the spatial differences in variability between different locations of the rainfall station. It was calculated using equation 1;

$$CV = \frac{Standard\ deviation}{Mean} \times 100 \qquad [1]$$

The magnitude of the trend in the seasonal and annual series was determined using Sen's estimator (Sen, 1968) and statistical significance of the trend was analyzed using Mann-Kendall (MK) test (Mann, 1945; Kendall, 1975). The Sen's slope method is non-parametric approach which gives a robust estimation of trend (Yue et al., 2002). It calculates the slope as a change in measurement in respect to change in time. The slope (S) is calculated by equation 2;

$$S_i = \frac{x_j}{j} \qquad [2]$$

For =1,2,3……, N

The S value is obtained by summing the counts of all the data series, x_i and x_j are the values of the series and i,j the years, being $i = j + 1$

where and are data values at times j and k ($j > k$), respectively. The median of these N values of is Sen's estimator of slope which is calculated as given in equation 3;

$$\beta = \begin{cases} T_{\frac{N+1}{2}} & N\ is\ c \\ \frac{1}{2}\left[T_{\frac{N}{2}} + T_{\frac{N+2}{2}}\right] & N\ is\ eve \end{cases} \qquad [3]$$

A positive indicates an upward (increasing) trend and a negative (decreasing) trend in the time series.

The MK was used to check the null hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. The statistic (S) is calculated using equation 4;

$$S = \sum_{i<j} \operatorname{sgn}(x_j - x_i) \qquad [4]$$

where, $\operatorname{sgn}(x_j - x_i) = \begin{cases} 1 & x_j > x_i \\ 0 & x_j = x_i \\ -1 & x_j < x_i \end{cases}$

This statistic represents a number of positive differences minus the number of negative difference for all the data considered. For a large sample (N>10), the test is conducted using a normal distribution with the mean and variance as expressed in equation 5;

$$E(S) = 0$$

$$\mathrm{Var}(S) = \frac{n(n-1)(2n+5)}{18} \quad [5]$$

The standard normal (Z-statistics) is then computed as shown in equation 6;

$$Z = \begin{cases} \frac{S-1}{\sqrt{var(s)}} \; if S > \\ 0 \quad if S = \\ \frac{S-1}{\sqrt{var(s)}} \; if S < \end{cases} \quad [6]$$

If the computed value of $Z > Z_{\alpha/2}$, the null hypothesis (H_o) is rejected (here $\alpha = 0.05$) level of significance in two sided test, but if of $Z < Z_{\alpha/2}$, then the null hypothesis for no trend is accepted. Failing to reject H_o (null hypothesis) does not mean that there is no trend. Rather, it is a statement that the evidence available is not sufficient to conclude if there is a trend (Helsel and Hirsch, 2002).

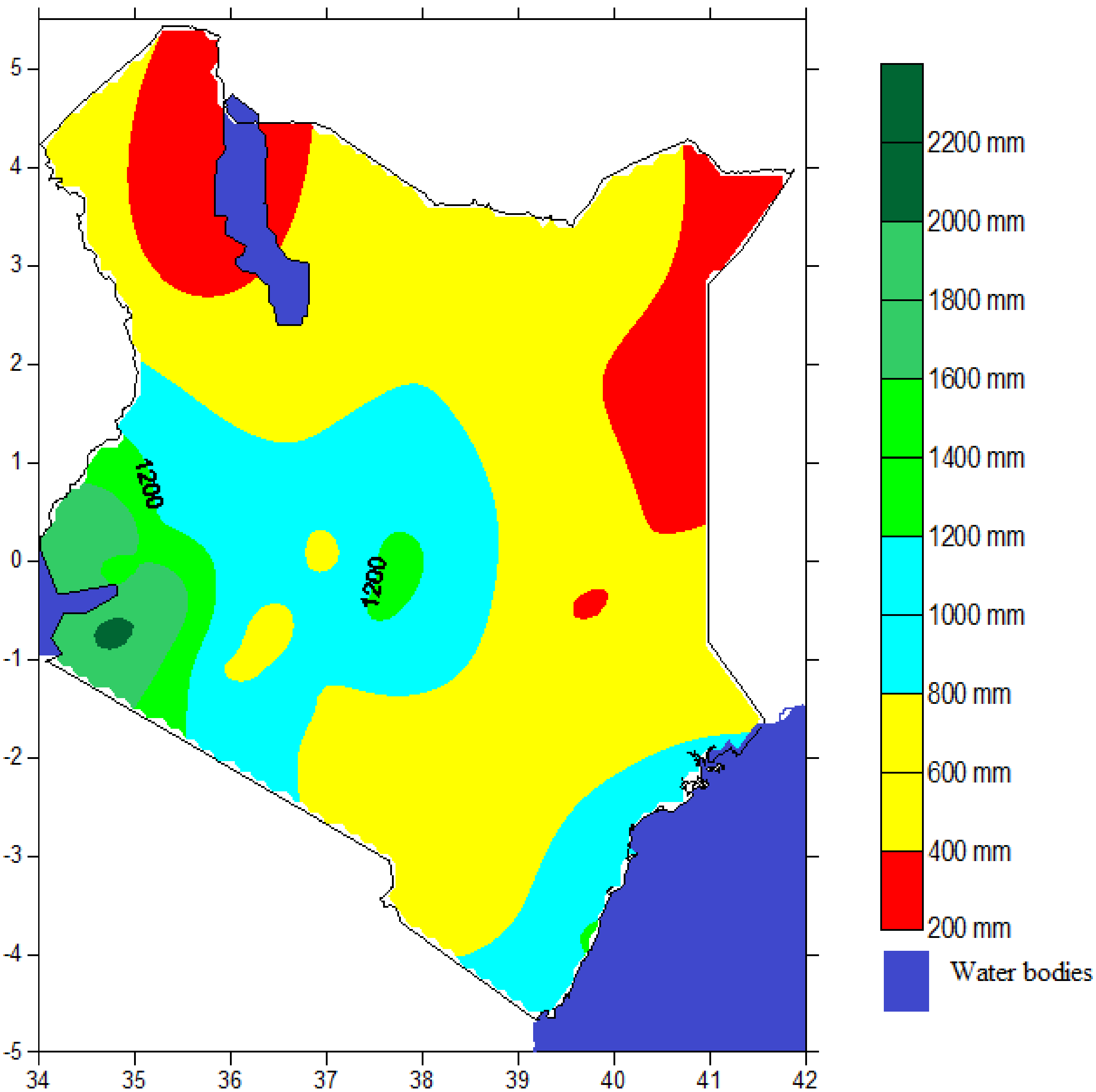

Fig. 2. Spatial distribution of average annual rainfall over Kenya.

Table 2. MAM and OND seasonal means (mm) for 33 stations and their percentage (%) contribution to the Annual rainfall

Station Name	MAM Mean Rainfall	OND Mean Rainfall	Annual Mean Rainfall	Contribution of MAM to Annual Rainfall	Contribution of OND to Annual Rainfall	Contribution of MAM & OND to Annual Rainfall
	(mm)			(%)		
Lodwar	99.7	50.3	215.3	46.3	23.3	69.6
Kericho	681.8	431.0	2023.1	33.7	21.4	55.1
Machakos	287.4	291.5	695.3	41.3	41.9	83.3
Kisumu	535.5	355.1	1388.6	38.6	25.6	64.1
Kisii	696.7	529.9	2105.0	33.1	25.2	58.3
Voi	192.5	280.6	566.3	34.0	49.6	83.6
Makindu	188.1	310.7	579.4	32.5	53.6	86.1
Marsabit	368.3	302.9	774.3	47.6	39.1	86.7
Narok	339.2	182.5	780.1	43.5	23.4	66.9
Kakamega	676.8	405.2	1970.3	34.3	20.6	54.9
Thika	441.9	332.7	935.19	47.3	35.6	82.8
Mtwapa	583.2	291.2	1291.1	45.2	22.6	67.7
Mombasa	454.9	285.4	1061.5	42.9	26.9	69.7
Embu	579.4	495.5	1269.1	45.7	39.0	84.7
Nyeri	418.2	303.4	938.7	44.5	32.3	76.9
Dagoretti	488.1	315.3	1034.2	47.2	30.5	77.7
Meru	459.6	686.1	1328.6	34.6	51.6	86.2
Kitale	441.5	261.7	1274.1	34.7	20.5	55.2
Nakuru	319.4	194.6	946.3	33.8	20.6	54.3
Nyahururu	274.0	190.5	998.1	27.5	19.1	46.5
Wajir	159.0	147.9	331.8	47.9	44.6	92.5
Moyale	360.1	247.7	707.1	50.9	35.0	86.0
Malindi	507.0	190.8	1075.4	47.1	17.7	64.9
Eldoret A.	328.5	162.0	1063.3	30.9	15.2	46.1
Mandera	143.6	120.0	277.2	51.8	43.3	95.1
Garissa	138.5	191.3	374.2	37.0	51.1	88.1
Lamu	455.7	152.6	954.8	47.7	16.0	63.7
Msabaha	513.5	237.2	1160.4	44.2	20.4	64.7
M.A.B	411.4	274.2	884.4	46.5	31.0	77.5
Wilson	426.7	285.4	923.2	46.2	30.9	77.1
JKIA	314.5	259.7	737.6	42.6	35.2	77.8
Nanyuki	242.6	208.1	690.3	35.1	30.2	65.3
Naivasha	250.6	179.6	668.9	37.5	26.8	64.3

3. Results and Discussion

3.1. Rainfall Variability

Spatial rainfall pattern (Fig. 2) and variability (Fig. 3) highlighted prevalence of wetter areas are in the western region bordering Lake Victoria, central highland of Rift Valley and part of coastal region with an annual mean rainfall ranging from 1000 to 2200 mm while, the dry areas confined to the northern part and south eastern region with an average rainfall of below 700 mm (Table 2).

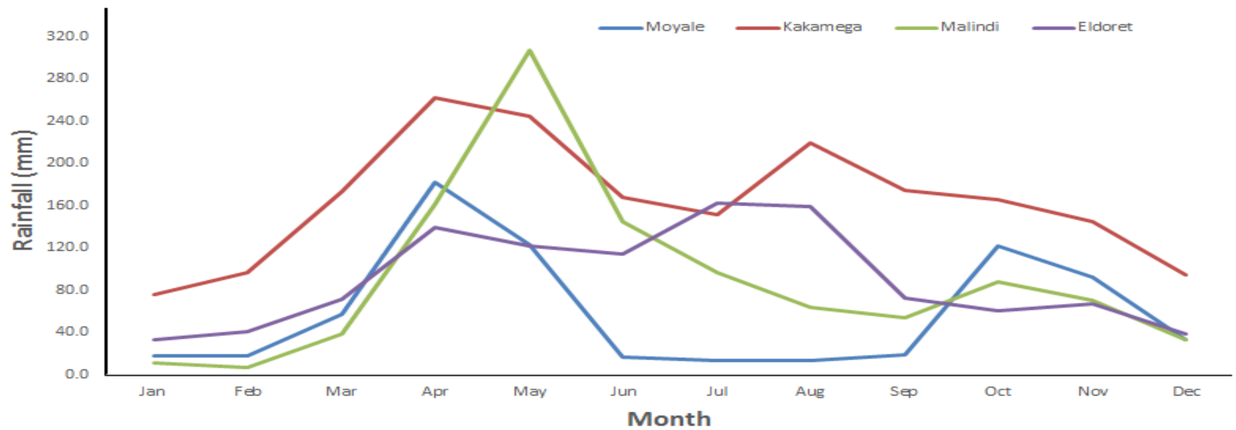

Fig. 3. Monthly rainfall variability for Moyale, Kakamega, Malindi and Eldoret Airport based on 1950 -2010 observed monthly dataset.

Table 3. The Mean, Standard deviation and Coefficient of Variability (CV) for March-April-May (MAM), October-November-December (OND) and Annual rainfall

Station Name	MAM			OND			ANNUAL		
	Mean	Standard Deviation	CV%	Mean	Standard Deviation	CV%	Mean	Standard Deviation	CV%
Lodwar	99.67	61.21	61.41	50.27	73.48	146.2	215.3	124.39	57.76
Kericho	681.79	138.80	20.36	432.97	160.86	37.15	2023.10	274.65	13.58
Machakos	287.44	120.22	41.82	291.46	148.49	50.95	695.27	204.25	29.38
Kisumu	535.45	136.56	25.50	355.07	191.73	54.00	1388.61	210.02	15.12
Kisii	696.70	159.20	22.85	529.86	196.13	37.02	2104.92	348.07	16.54
Voi	192.54	89.38	46.42	280.58	120.98	43.12	566.03	185.16	32.71
Makindu	188.10	95.21	50.62	310.68	174.83	56.27	579.36	219.8	37.94
Marsabit	368.29	181.22	49.21	302.88	209.21	69.07	774.28	317.12	40.96
Narok	339.24	121.53	35.82	182.5	118.45	64.91	780.14	200.30	25.68
Kakamega	676.80	128.78	19.03	405.22	182.28	44.98	1970.33	295.78	15.01
Thika	441.94	172.97	39.14	332.70	164.93	49.57	935.19	264.92	28.33
Mtwapa	583.24	229.06	39.27	291.16	227.39	78.1	1291.07	367.56	28.47
Mombasa	454.91	196.23	43.14	285.37	204.63	71.71	1061.51	326.82	30.79
Embu	579.38	207.00	35.73	495.45	185.62	37.47	1269.05	300.81	23.70
Nyeri	418.18	149.20	35.68	303.39	157.46	51.9	938.72	231.81	24.69
Dagoretti	488.12	176.25	36.11	315.3	171.8	54.5	1034.24	248.37	24.01
Meru	459.63	178.88	38.92	686.06	288.18	42.01	1328.57	366.08	27.55
Kitale	441.54	120.04	27.19	261.68	109.5	41.84	1274.08	189.11	14.84
Nakuru	319.43	117.7	36.85	194.57	83.57	42.95	946.32	188.6	19.93
Nyahururu	273.99	113.67	41.49	190.52	134.1	70.38	998.11	238.23	23.87
Wajir	158.96	106.79	67.18	147.91	150.73	101.9	331.78	191.40	57.69
Moyale	360.1	142.0	39.44	247.73	165.13	66.66	707.1	238.4	33.72
Malindi	506.98	182.08	35.92	190.78	139.19	72.96	1075.42	284.66	26.47
Eldoret A.	328.46	113.21	34.47	162.03	111.29	68.68	1063.25	224.70	21.13
Mandera	143.62	82.92	57.74	119.98	127.54	106.31	277.18	154.95	55.90
Garissa	138.48	97.3	70.26	191.27	125.44	65.58	374.24	190.02	50.77
Lamu	455.65	223.50	49.05	152.55	154.7	101.4	954.81	317.0	33.2
Msabaha	513.46	194.55	37.89	237.16	189.46	79.89	1160.42	366.02	31.54
M.A.B	411.4	186.11	45.24	274.17	114.45	41.74	884.44	254.43	28.77
Wilson	426.73	166.65	39.05	285.38	151.1	52.95	923.22	230.93	25.01
JKIA	314.48	130.51	41.50	259.71	156.33	60.19	737.57	219.59	29.77
Nanyuki	242.62	91.53	37.73	208.14	89.13	42.82	690.33	186.25	26.98
Naivasha	250.61	90.99	36.31	179.6	91.33	50.85	668.94	132.46	19.80

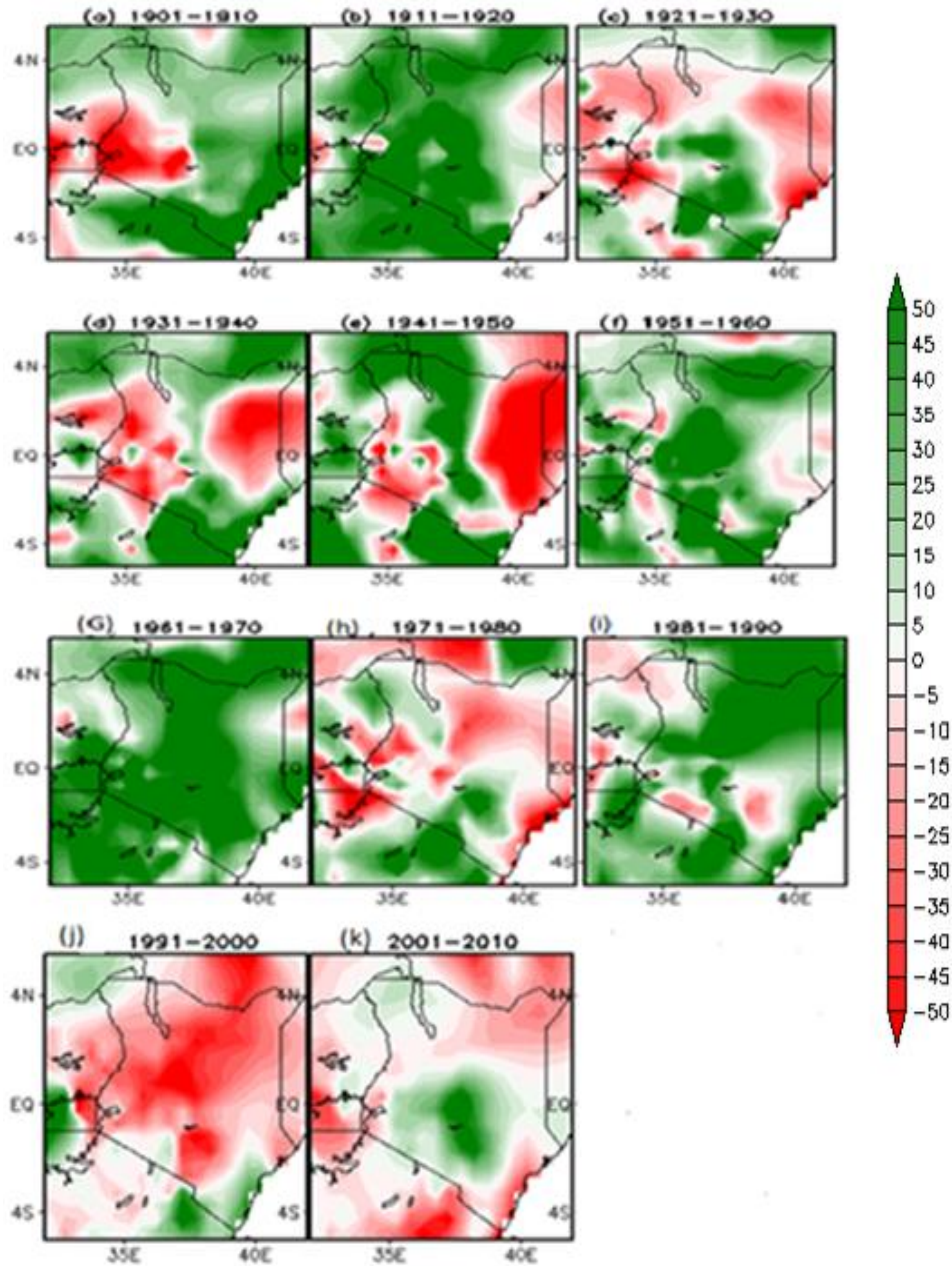

Fig. 4. Decadal March-May rainfall anomaly relative to base period (1984 – 2014) average rainfall over Kenya.

Table 4. Mann-Kandall (MK) statistics, Sen's slope and P-value for MAM, OND and Annual for different station (highlighted in red show statistical significant at 5% level)

Station Name	MAM			OND			ANNUAL		
	MK	Sen's slope	p-Value	MK	Sen's slope	p-Value	MK	Sen's slope	p-Value
Lodwer	-0.046	-0.226	0.598	0.066	0.106	0.451	0.01	0.085	0.92
Kericho	-0.109	-2.168	0.336	0.279	0.012	6.01	-0.072	-2.44	0.532
Machakos	-0.060	-0.718	0.520	-0.031	-0.199	0.740	-0.070	-1.383	0.450
Kisumu	-0.086	-1.12	0.363	-0.024	-0.27	0.800	0.010	0.138	0.917
Kisii	0.102	1.7	0.300	0.050	0.671	0.616	0.063	1.89	0.525
Voi	-0.010	-0.065	0.915	0.097	1.067	0.262	0.044	0.743	0.618
Makindu	-0.067	-0.375	0.441	-0.033	-0.304	0.704	-0.030	-0.574	0.731
Marsabit	-0.283	-2.407	0.020	-0.032	0.433	0.717	-0.138	-3.723	0.111
Narok	-0.137	-1.46	0.115	-0.021	-0.171	0.812	-0.123	-2.035	0.155
Kakamega	0.016	0.254	0.867	0.119	1.551	0.201	-0.013	-0.392	0.896
Thika	-0.031	-0.544	0.740	0.168	2.11	0.069	0.073	1.726	0.433
Mtwapa	0.010	0.289	0.917	0.153	1.847	0.104	-0.009	-0.197	0.929
Mombasa	-0.078	-1.656	0.400	-0.016	-0.079	0.871	-0.131	-3.395	0.155
Embu	-0.069	-1.49	0.559	0.057	1.202	0.631	-0.027	-1.28	0.825
Nyeri	0.044	0.838	0.676	0.162	2.45	0.120	0.073	2.45	0.490
Dagoretti	-0.036	-0.544	0.697	0.099	1.1	0.277	-0.005	-0.134	0.957
Meru	-0.162	-3.04	0.111	0.067	1.8	0.515	-0.014	-0.444	0.898
Kitale	-0.005	-0.075	0.977	0.301	5.062	0.012	0.094	4.733	0.444
Nakuru	0.053	0.636	0.601	0.286	2.04	0.004	0.063	1.24	0.531
Nyahururu	0.050	0.564	0.608	0.039	0.366	0.687	0.011	0.341	0.918
Wajir	-0.120	-0.706	0.167	0.101	0.66	0.243	0.026	0.303	0.767
Moyale	-0.245	-2.77	0.005	-0.082	-0.86	0.343	-0.228	-3.52	0.008
Malindi	-0.050	-0.923	0.608	0.055	0.709	0.570	-0.083	-1.995	0.390
Eldoret A.	0.000	-0.022	0.991	0.232	3.52	0.033	0.117	3.86	0.288
Mandera	-0.173	-1.088	0.061	0.031	0.207	0.745	-0.029	-0.437	0.761
Garissa	-0.113	-1.093	0.230	-0.022	-0.177	0.823	-0.111	-1.45	0.239
Lamu	-0.045	-0.854	0.610	0.327	2.711	0.000	0.117	2.71	0.178
Msabaha	-0.008	-0.155	0.938	0.082	1.00	0.377	-0.029	-0.673	0.761
M.A.B	-0.018	-0.291	0.865	0.142	1.49	0.168	0.047	1.57	0.651
Wilson	-0.100	-1.895	0.280	0.169	1.712	0.067	-0.035	-0.815	0.708
JKIA	-0.041	-0.508	0.663	0.041	0.369	0.663	-0.058	-1.363	0.537
Nanyuki	-0.134	-1.236	0.147	-0.206	-1.024	0.025	-0.166	-2.635	0.073
Naivasha	-0.109	-1.00	0.259	-0.021	-0.172	0.831	-0.050	-0.77	0.608

Most of the stations displayed bimodal rainfall characteristics with exception of some station over western region which displayed a trimodal pattern (Fig. 4). For the bimodal, the rainfall seasons are; March April May, whereby the rains start in March and peak in April and ends in May (Fig. 4a) with exception of coastal stations (Mombasa, Mtwapa, Msabaha and Malindi) (Fig 4c) which had their peaks in May and ends in June. The second rain season begins in October ends in December with a peak in November. Western region has a third rain season; June to August (Fig 4b and d). It is worth nothing that Eldoret Airport station has its main rainfall in June to August season (Fig. 3d). The results are in agreement with the precipitation trends reported by previous studies (Davies and Vincent, 1985; Ininda 1994; Liebmann et al., 2014; Yang et al., 2015; Ongoma and Chen, 2016).

The analysis of the contribution of the two main rainfall season (MAM and OND) to the annual rainfall, shows that MAM contribute between 30 to 50% of the annual rainfall, with the lowest percentage in Nyahururu station which contribute 27% of the total annual rainfall in that station and the highest in Mandera station at 51.8% of the total annual rainfall (Table 2). On the other hand, OND season contribution ranges from as low as 16% in Lamu station to as high as 53.6% in Makindu station. It was also noted that the south eastern lowland (Voi, Makindu, Machakos) much of its annual rainfall is from the short rain season (OND).

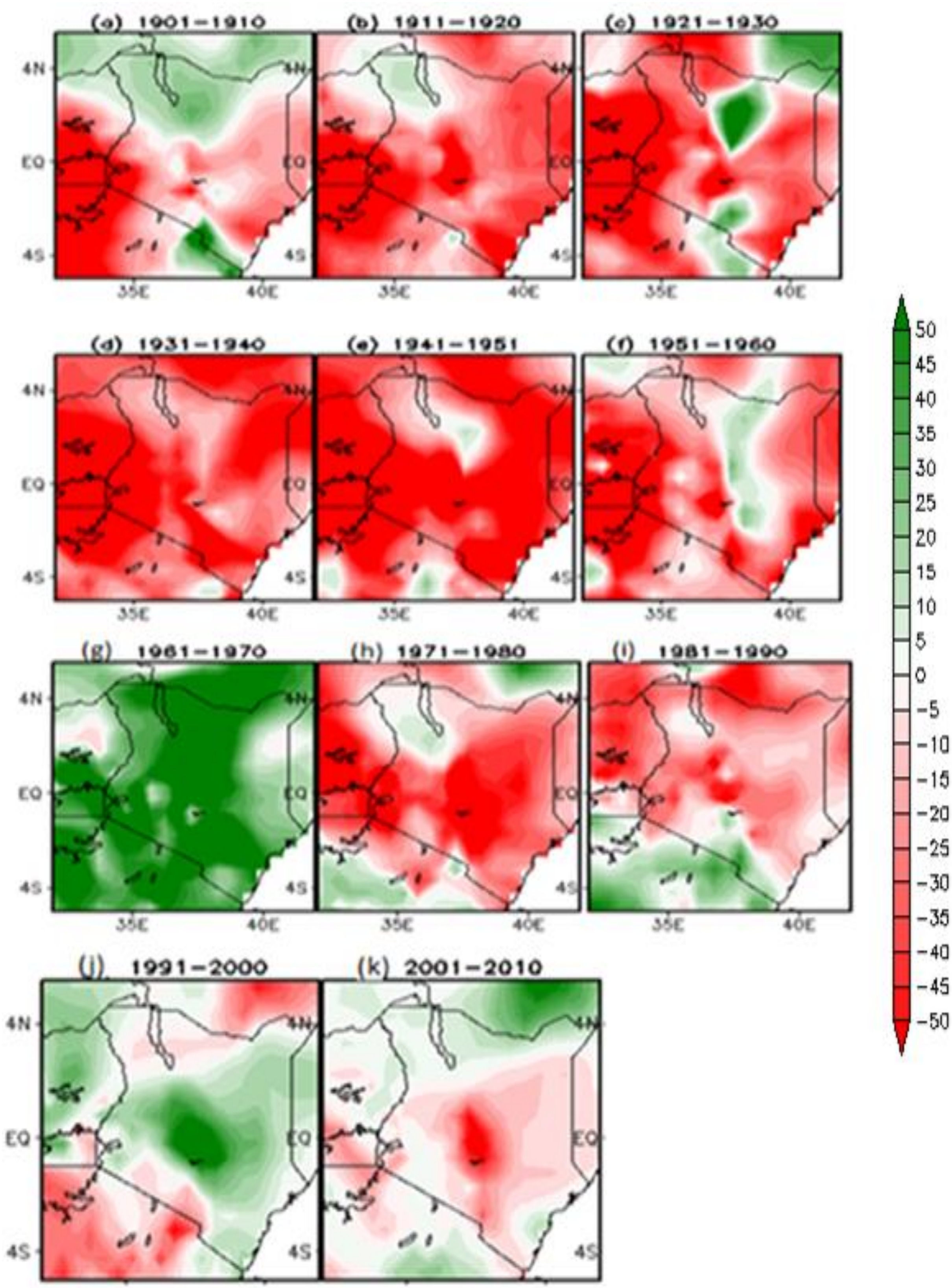

Fig. 5. Decadal October-December (OND) rainfall anomaly relative to base period (1984 – 2014) average rainfall over Kenya.

The two main seasons contributed less than 50% of the annual rainfall for Eldoret and Nyahururu station, JJA is the main rainfall season for the two stations. Overly, the two seasons (MAM and OND) are important rainfall season for Kenya and any changes in the trend will likely affect the economy which majorly relies on rain fed agriculture.

OND season displayed a high degree of variability, with 67% of all stations (22) recording CV greater than 50%, while the MAM season had a low variability with only five stations recording CV of more than 50% (Table 4).

On the other hand, the annual rainfall had a low variability with only four stations having CV of greater than 50%. On spatial scale, stations in the arid areas had high CV greater than 50% for both seasons (MAM and OND). The wet areas (Western and Central highlands) had a low CV (Table. 2). CV measures the reliability of rainfall and the low value indicates very reliable rainfall and vise verse. Therefore, short rains with high variability are unreliable as compared to long rains. The high variability in short rains is connected with the large scale factors: El Nino southern Oscillation Index (ENSO) and Indian Ocean Dipole (IOD), which results to more inter-annual variability. The two synoptic systems: ENSO and IOD are known to influence OND rainfall more than as it does to MAM rainfall (Liebmann et al., 2014; Ogallo, 1988; Ogallo, 1989).

3.2. Trend Analysis

Figures 4 and 5 show decadal rainfall anomaly for MAM and OND seasons, respectively, for a base period 1984 – 2014. From the Figure 4, it is evident that the last two decades: 1990s and 2000s, MAM season has experienced the highest reduction in rainfall, relative to the long term mean of 1984 to 2014. The earlier decades of 1911 – 1920, 1961 – 1970s where the wettest (excessive rainfall) decade relative to long term mean. For the OND season, the earlier decades of 1901 to 1950, has been the driest compared to the recent decade of 1991 to 2010, which have shown a significant increase in rainfall during this season (Fig. 5).The reduction in rainfall during MAM season and significant increase in OND season concur with the observation made in recent studies by Liebmann et al. (2014) and Yang et al. (2014).

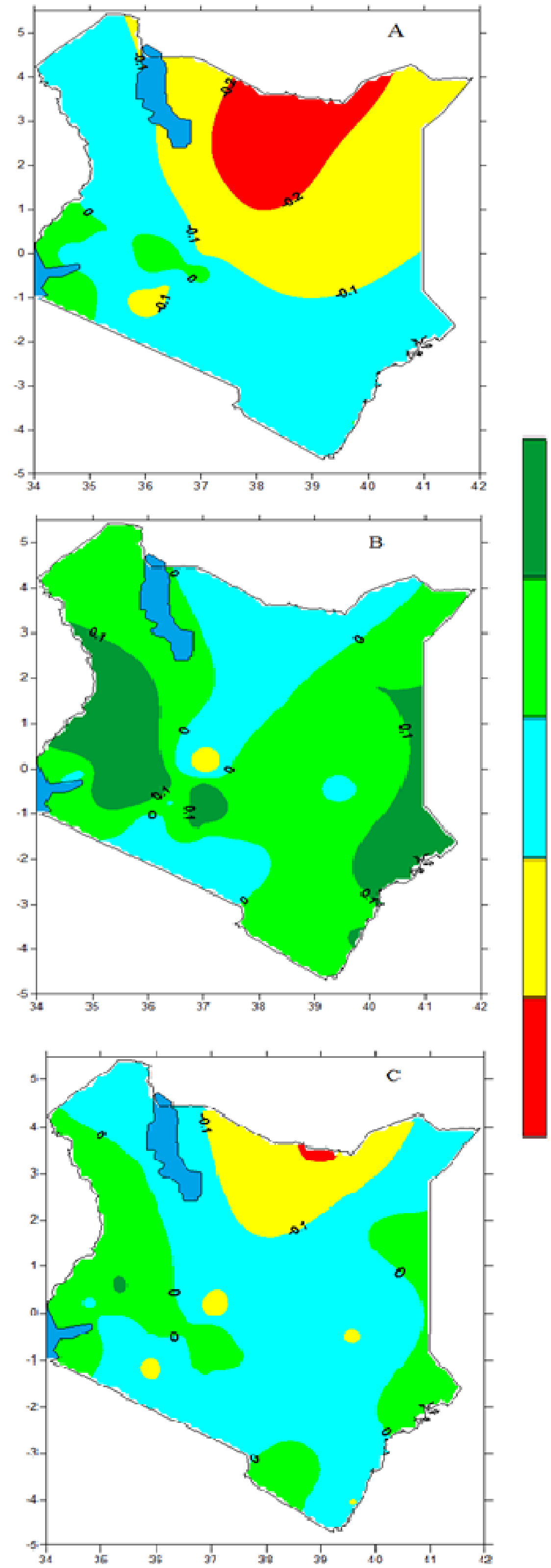

Fig. 6. Spatial distribution of MAM (A), OND (B) and Annual (C). Mann-Kendall (MK) at 5% level of significance.

From the trend analysis, a declining trend was noted in MAM season and increasing trend in OND season for most of the station analyzed (Table 4, Fig. 6). However, the trends are statistically insignificant at 5% significance level for both seasons. But some stations (Marsabit and Moyale) displayed statistically significance decreasing trend for MAM season, while Kitale and Nakuru stations had a significant increasing trend for OND season (Fig. 3). Nanyuki displayed a statistically significant decreasing trend for OND season.

Insignificant trends were noted in all station for annual rainfall, with exception of Moyale which had significantly decreasing trend of 3.52 mm/year (Table 4). The increase in OND rainfall has been attributed to the warming of the western Indian Ocean (Liebmann et al., 2014). Yang et al. (2014) observed that the decrease in MAM rainfall over East Africa, and attributed this to natural decadal variability rather than anthropogenic influence.

4. Conclusion

The trends and variability of rainfall data were analyzed for different stations for a period ranging from 1950 – 2012. High variability was noted during the 'short rain' season as compared to 'long rain' season. On spatial scale, the stations in the northern region of the study area showed higher CV (>50%) than other station in both seasons hence, a high annual rainfall variability. It was also observed that in recent years, March-May rainfall had decreased compared to long term mean of 1984 – 2014, while that of OND increased during the same period. This was confirmed by the trend analysis of the observed station data; it was found out that MAM rainfall had an insignificant decrease at 5% significant level, while that of OND had an insignificant increase in rainfall at the same significance level. The annual rainfall showed an insignificant decreasing and increasing trend for different stations, with only one station Moyale showing a statistically significant decrease in annual rainfall (3.52 mm/ year). The results give a basis for further analysis on the impact of this reduction/increase in the different sectors of the economy that are rainfall dependent.

List of abbreviations: CV: Coefficient of Variation; OND: October-November- December; MAM: March-April-May.

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Author Contribution: POS analyzed the data and wrote the paper, and all authors discussed the results and implications and commented on the manuscript at all stages. All authors contributed extensively to the work presented in this paper.

References

Ahmed, M., M. Sultan, J. Wahr and E. Yan. 2014. The use of GRACE data to monitor natural and anthropogenic induced variations in water availability across Africa. Earth-Sci. Rev. 136: 289-300.

Amin, A., W. Nasim, M. Mubeen, S. Sarwar, P. Urich, A. Ahmad, A. Wajid, T. Khaliq, F. Rasul, H.M. Hammad, M.I.A. Rehmani, et al., 2018. Regional climate assessment of precipitation and temperature in Southern Punjab (Pakistan) using SimCLIM climate model for different temporal scales. Theor. Appl. Climatol. 131(1): 121-131.

Anyah, R. O. and F. H. M. Semazzi. 2006. Climate variability over the Greater Horn of Africa based on NCAR AGCM ensemble. Theor. Appl. Climatol. 86: 39–62.

Anyamba, E. K. and P. M. R. Kiangi. 1985. Mean motion fields in East Africa at the level of East African Level Jet Core. Arch. Met. Geoph. Biocl. Sev. B. 36: 29-41.

Asnani and Kinuthia. 1979. Diurnal variation of precipitation in East Africa. Republic of Kenya, Meteorological Dept., Nairobi, Kenya, Research report-No. 8:1-58.

Awuor, C.B., V.A. Orindi and A.O. Adwera. 2008. Climate change and coastal cities: the case of Mombasa, Kenya. Environ. Urbanization. 20(1): 231-242.

Battisti, D.S. and R.L. Naylor. 2009. Historical Warnings of future food insecurity with unprecedented seasonal heat. Science. 323(5911): 240-244.

Ben-Mohamed, A. 2010. Climate Change Risks in Sahelian Africa. Reg. Environ. Chang. 11(1): 109-117.

Berhane, F., and B. Zaitchik. 2014. Modulation of daily precipitation over East Africa by the Madden-Julian oscillation. J. Climate. 27(15): 6016–6034.

Black, E., J.M. Slingo, and K.R Sperber. 2003. An observational study of the relationship between excessively strong short rains in coastal East Africa and Indian Ocean SST. Monthly Weather Rev. 74–94.

Camberlin, P. and N. Philippon. 2002. The East African March – May Rainy Season : Associated Atmospheric Dynamics and Predictability over the 1968 – 97 Period. J. Climate. 15:1002–1019.

Challinor, A.J., J. Watson, D.B. Lobell, S.M. Howden, D.R. Smith and N. Chhetri. 2014. A meta-analysis of crop yield under climate change and adaptation. Nat. Clim. Change. 4: 287.

Conway, D., E.A. van Garderen, D. Deryng, S. Dorling, T. Krueger, W. Landman, B. Lankford, K. Lebek, T. Osborn, C. Ringler, J. Thurlow, T. Zhu and C. Dalin. 2015. Climate and southern Africa's water–energy–food nexus. Nat. Clim. Change. 5: 837.

Darand, M., M. Dostkamyan and M.I.A. Rehmani. 2017. Spatial autocorrelation analysis of extreme precipitation in Iran. Russian Meteorol. Hydrol. 42(6): 415-424.

Davies, T. D., C. E. Vincent and A. K. C. Beresford. 1985. July-August rainfall in West-Central Kenya. Int. J. Climatol. 5: 17-33.

Eakin, H. and A.L. Luers. 2006. Assessing the vulnerability of social-environmental systems. Annu. Rev. Environ. Resour. 31: 365-394.

Farmer, G. 1988. Seasonal forecasting of the Kenya Coast short rains 1901-84. J. Climate: 8: 489-497.

Forsythe, N., H.J. Fowler, X.-F. Li, S. Blenkinsop and D. Pritchard. 2017. Karakoram temperature and glacial melt driven by regional atmospheric circulation variability. Nat. Clim. Change. 7: 664.

Funk, C., M.D. Dettinger, J.C. Michaelsen, J.P. Verdin, M.E. Brown, M. Barlow and A. Hoell. 2008. Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. Proc. Nat. Acad. Sci. 105: 11081–11086.

Funk, C., M.D. Dettinger, J.C. Michaelsen, J.P. Verdin, M.E. Brown, M. Barlow and A. Hoell. 2008. Warming of the Indian Ocean threatens eastern and southern African food security but could be mitigated by agricultural development. Proc. Nat. Acad. Sci. 105(32): 11081-11086.

Gao, R., F. Li, X. Wang, T. Liu, D. Du and Y. Bai. 2017. Spatiotemporal variations in precipitation across the Chinese Mongolian plateau over the past half century. Atmos. Res. 193: 204-215.

Haile, M. 2005. Weather patterns, food security and humanitarian response in sub-Saharan Africa. Philos. Trans. Royal Soc. B: Biol. Sci. 360(1463): 2169-2182.

Harris, I., P.O. Jones, T.J. Osborn and D.H. Lister. 2014. Updated high-resolution grids of monthly climatic observations - The CRU TS3.10 dataset. Int. J. Climatol. 34: 623–642.

He, J., C. Deser and B.J. Soden. 2017. Atmospheric and oceanic origins of tropical precipitation variability. J. Clim. 30(9): 3197-3217.

Helsel, D.R. and R.M. Hirsch. 2002. Statistical methods. Water resources techniques of water resources investigations, No. 4. U.S. Geological Survey. 522.

Hogan E., A. Shelly and P. Xavier. 2015 The observed and modelled influence of the Madden–Julian Oscillation on East African rainfall. Meteorol Apps. 22: 459–469.

Hulme, M., R. Doherty, T. Ngara, M. New and D. Lister. 2001. African climate change: 1900-2100. Clim. Res. 17: 145-168.

Indeje, M., F. H. M. Semazzi, L. Xie, and L. J. Ogallo. 2001. Mechanistic model simulations of the East African Climate using NCAR Regional Climate Model: Influence of large scale orography on the Turkana Low-Level Jet. J. Clim.14: 2710 -2724.

Ininda, J. M. 1995. Numerical stimulation of the influence of sea surface temperatures (SST) anomalies on East African seasonal rainfall. Ph.D. Thesis, University of Nairobi, Kenya.

IPCC, 2007.Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden and C.E. Hanson, Eds., Cambridge University Press, Cambridge, UK, p. 976.

IPCC, 2014.Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, p. 151.

Kabubo-Mariara, J. and F.K. Karanja. 2007. The economic impact of climate change on Kenyan crop agriculture: A Ricardian approach. Global Planet. Change. 57(3): 319-330.

Kendall, M. G., 1975: Rank correlation methods, Charles Griffin, Lomdon. UK.

Knapp, A.K., P. Ciais, M.D. Smith. 2017. Reconciling inconsistencies in precipitation–productivity relationships: implications for climate change. New Phytol. 214(1): 41-47.

Li, X., X. Wang, V. Babovic. 2018. Analysis of variability and trends of precipitation extremes in Singapore during 1980–2013. Int. J. Climatol. 38(1): 125-141.

Liebmann, B., M. P. Hoerling, C. Funk, I. Blade, R. M. Dole, D. Allured, X. Quan, P. Pegion and J. K. Eischeid. 2014. Understanding recent Eastern Horn of Africa rainfall variability and change. J. Cliamate. 27: 8630–8645.

Lobell, D.B., M.B. Burke, C. Tebaldi, M.D. Mastrandrea, W.P. Falcon and R.L. Naylor. 2008. Prioritizing climate change adaptation needs for food security in 2030. Science. 319: 607-610.

Mann, H. B. 1945. Non-parametric test against trend. Econometrica. 13: 245-259.

Mati, B.M. 2000. The influence of climate change on maize production in the semi-humid–semi-arid areas of Kenya. J. Arid Environ. 46(4): 333-344.

Meehl, G. A., T. Karl, D.R. Easterling, S. Changnon, R. PielkeJr, D. Changnon, J. Evans, P.Y. Groisman, T.R. Knutson, K.E. Kunkel, L.O. Mearns, et al. 2000. An introduction to trends in extreme weather and climate events: Observations, socioeconomic impacts, terrestrial ecological impacts, and model projections. Bull. Am. Meteor Soc.81:413–416.

Milly, P.C.D., K.A. Dunne and A.V. Vecchia. 2005. Global pattern of trends in stream flow and water availability in a changing climate. Nature. 438: 347–350.

Moyo, M., B.M. Mvumi, M. Kunzekweguta, K. Mazvimavi, P. Craufurd and P. Dorward. 2012. Farmer perceptions on climate change and variability in semi-arid Zimbabwe in relation to climatology evidence. J. Afr. Crop Sci. 20: 317-335.

Mutai, C.C. and M.N. Ward. 2000. East African rainfall and the tropical circulation/convection on intraseasonal to interannual timescales. J. Clim. 13:3915–3939.

Muthoni, J., D.O. Nyamongo and M. Mbiyu. 2017. Climatic change, its likely impact on potato (*Solanum tuberosum* L.) production in Kenya and plausible coping measures. Int. J. Hort. 7(14): 115-123.

Ngaina, J. and B. Mutai. 2013. Observational evidence of climate change on extreme events over East Africa. Global Meteorol. 2(1): e2.

Ngetich, K.F., M. Mucheru-Muna, J.N. Mugwe, C.A. Shisanya, J. Diels and D.N. Mugendi. 2014. Length of growing season, rainfall temporal distribution, onset and cessation dates in the Kenyan highlands. Agric. Forest Meteorol.188: 24–32.

Niang, I., O.C. Ruppel, M.A. Abdrabo, A. Essel, C. Lennard, J. Padgham, and P. Urquhart. 2014. Africa. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Barros, V.R., C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA, p. 1199-1265.

Nicholson, S.E. 2016. An analysis of recent rainfall conditions in eastern Africa. Int. J. Climatol. 36: 526–532.

Nyakwada, W. 2009. Predictability of East African seasonal rainfall with sea surface temperature gradient modes. PhD Thesis, University of Nairobi, Kenya.

Ochieng, J., L. Kirimi and M. Mathenge. 2016. Effects of climate variability and change on agricultural production: The case of small scale farmers in Kenya. NJAS - Wageningen J. Life Sci. 77: 71-78.

Ogallo, L. 1988. Relationships between seasonal rainfall in East Africa and the Southern Oscillation. J. Climate. 8: 31–43.

Ogallo, L. 1989. The spatial and temporal patterns of the East African seasonal rainfall derived from principal component analysis. Int. J. Climatol. 9:145–167.

Ogallo, L.J., J.E. Janowiak and M.S. Halpert. 1988. Teleconnection between seasonal rainfall over East Africa and global seas surface temperature anomalies. J. Meteorol. Soc. Japan. 66: 807–822.

Ogwang, B.A., H. Chen, G. Tan, V. Ongoma, and D. Ntwali. 2015. Diagnosis of East African climate and the circulation mechanisms associated with extreme wet and dry events: a study based on RegCM4. Arab. J. Geosci. 8: 10255-10265.

Ongoma, V. and H. Chen. 2017. Temporal and spartial variability of temperature and precipitation over East Africa from 1951 to 2010. Meteorol. Atmos. Phys. 129: 131-144.

Ongoma, V., J.N. Muthama, and W. Gitau. 2013. Evaluation of urbanization on urban temperare of Nairobi City, Kenya. Glob. Meteorol. 2:e1.

Ongoma, V., T. Guirong, B.A. Ogwang, and J.P. Ngarukiyimana. 2015. Diagnosis of Seasonal

Rainfall Variability over East Africa : A Case Study of 2010-2011 Drought over Kenya. Pakistan J. Meteorol. 11: 13–21

Opiyo, F., M. Nyangito, O.W. Oliver, and P. Omondi. 2014. Trend Analysis of Rainfall and Temperature Variability in Arid Environment of Turkana, Kenya. Environ. Res. J. 8: 30-43.

Owiti, Z., L. A. Ogallo, and J. Mutemi. 2008. Linkages between the Indian Ocean Dipole and east African seasonal rainfall anomalies. J. Kenya Meteorol. Soc. 2(1):3 –17.

Preston, B.L., E.J. Yuen and R.M. Westaway. 2011. Putting vulnerability to climate change on the map: a review of approaches, benefits, and risks. Sustain Sci. 6: 177-202.

Rehmani, M.I.A., G. Wei, N. Hussain, C. Ding, G. Li, Z. Liu, S. Wang and Y. Ding. 2014. Yield and quality responses of two indica rice hybrids to post-anthesis asymmetric day and night open-field warming in lower reaches of Yangtze River delta. Field Crops Res. 156: 231-241.

Sen, P. K.1968. Estimates of the Regression Coefficient Based on Kendall's Tau. J Amer Stat Assoc 63:1379–1389.

Shisanya, C. A., C. Recha, and A. Anyamba. 2011. Rainfall Variability and Its Impact on Normalized Difference Vegetation Index in Arid and Semi-Arid Lands of Kenya. Int. J. Geosci., 2:36-47.

Siam, M.S., E.A.B. Eltahir. 2017. Climate change enhances interannual variability of the Nile river flow. Nat. Clim. Change. 7: 350.

Silva, V.P.R. 2004. On climate variability in North-East of Brazil, J. Arid Environ. 58: 575-596.

Sun, Q., C. Miao, Q. Duan, H. Ashouri, S. Sorooshian and K.-L. Hsu. 2018. A Review of Global Precipitation Data Sets: Data Sources, Estimation, and Intercomparisons. Rev. Geophys. (Accepted Article). doi: 10.1002/2017RG000574.

Vorosmarty, C.J., P. Green, J. Salisbury and R.B. Lammers. 2000. Global water resources: Vulnerability from climate change and population growth. Science. 289(5477): 284-288.

Wagesho, N., N.K. Goel and M.K. Jain. 2013. Temporal and spatial variability of annual and seasonal rainfall over Ethiopia. Hydrol. Sci. J. 58: 354-373.

Wakachala, F. M., Z. W. Shilenje., J. Nguyo, S. Shaka, and W. Apondo. 2015. Statistical patterns of rainfall variability in the Great Rift Valley of Kenya. J. Environ. Agric. Sci. 5: 17-26.

Xia, J., L. Ning, Q. Wang, J. Chen, L. Wan and S. Hong. 2017. Vulnerability of and risk to water resources in arid and semi-arid regions of West China under a scenario of climate change. Clim. Change. 144(3): 549-563.

Yang, W., R. Seager, M.A. Cane and B. Lyon. 2014. The East African long rains in observations and models. J. Climate. 27: 7185–7202.

Yang, W., R. Seager, M.A. Cane and B. Lyon. 2015. The Annual Cycle of the East African Precipitation. J. Climate 28: 2385 – 2404.

Yue, S., P. Pilon, and G. Cavadias. 2002. Power of the Mann-Kendall and Spearman's Rho tests for detecting monotonic trends in hydrologic series. J. Hydrol. 259: 254-271.

Zhang, Q., F. Zhang, S. Kang and Z. Cong. 2017. Melting glaciers: Hidden hazards. Science. 356(6337): 495-495.

Zhang, Z. 2018. Climate Modeling. In: Multivariate Time Series Analysis in Climate and Environmental Research. Springer International Publishing, Cham, p. 205-216.

Zuo, D., Z. Xu, D. Peng, J. Song, L. Cheng, S. Wei, K.C. Abbaspour and H. Yang. 2015. Simulating spatiotemporal variability of blue and green water resources availability with uncertainty analysis. Hydrol. Process. 29(8): 1942-1955.