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Spatio-temporal assessment of rainfall influence on vegetation in the arid and semi-arid lands of Kenya

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Abstract: *Climate controls the types, health and spatial distribution of vegetation. The rainfall patterns and vegetation distribution have a very high correlation especially within the tropics. The higher and the more evenly distributed the rainfall is, the more the vegetation cover. However, in the arid and semi-arid lands, the rainfall is seasonal and has very high variability thereby affecting the availability of pasture for both livestock and wildlife, critical economic activities.The research was accomplished byspatio-temporaltrend analysis of Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI) data of fifteen years (2001-2015). The spatial data was sourced from USGS, ILRI, and United Nations Africover Project. The data processing and analysis was done usingArcGIS, Map Comparison Kit and Geodasoftwares.The research found out that:The monthly rainfall trend ranged from -15 – 20mm while the annual trend indicated a reduction of -6 – 0mm in the entire country which shifted spatially in some months and years; the monthly MODIS NDVI trend was between-0.065 - 0.060 and also depicted spatial shift in some months; the dependence of MODIS NDVI on rainfall was significant with annual coefficients of determination of 0.541 in 2002 and 0.763 in 2006 and the fifteen years mean at 0.617; and MODIS NDVI did not show evidence of spatial shift. The research concluded that therainfall rangeland vegetation (grass) temporal distribution has changed both with time, seasons and spatially.*

Keywords: *Rangeland,grass, climate change, spatial, temporal, arid and semi-arid lands*

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I. Introduction

Climate change is real and has varied local, regional and global impacts [1]. The relation between climate and rangeland vegetation as concluded by [2] are normally highly correlated. The rangeland ecosystems have enormous ecological and economic benefits. Ecologically, it is home to many animals and plants species which are utilized by man in various ways. The pasture is used for livestock grazing while the wildlife forms the major tourism attractions in the country [3].The rangelands according to [4]are defined aslarge open areas containing plants mainly grass and shrubs used for grazing. The rangeland vegetation depends entirely on climate which has been documented to change by various researchers [5]; [1].

Scientists have unearthed evidenced that the earth has warmed up by an average of about 0.6^{o}C since the late 19th centuryand is projected that the temperature will increase by 1.4^{o}C – 5.8^{o}C by the year 2100 at a global scale[5]. Temperature anomalies in Kenya are reported to be 0.4 – 1.6^{O}C with climate change related deaths of 70 – 120 per million population[6]. The repercussions of these climate anomalies among others include changes in land use land cover in both time and space [7] and the entire ecosystems. This will disrupt the economic activities directing depending on rangeland vegetation. [8] findings indicate that developing countries such as Kenya will be hit most due to various reasons includingthe fact that Kenya's economy is largely dependent on agriculture and tourism.

A large part of Kenya about 80% is classified as arid and semi-arid lands (ASALs) and is prone to drought and floods. Many livestock keeping communities, ranches, and game reserves are located in these regions of Kenya.Also, the country's population is growing and people are migrating to these fragile ecosystems increasing pressure on the limited vegetation resources [9]. This paper consequently seeksto establish both the temporal and spatial nature of climate based rangeland vegetation change in the ASALs of Kenya to aid decision making.

II. Materials and Methods

2.1 Study area

Kenya is located in the East African region covering a total of 582,646 km^2 with about 80% of it classified as arid and semi-arid lands(Fig. 1). It is within 5°26′N and 4°50′S with the equator dividing the country into almost two equal halves and within 34°00′E and 42°00′E. The rainfall patterns of the country are varied depending on regions with ASALs having rainfall of about 200mm to less than 500mm and temperature range of 0^oC in Mt. Kenya to 40^oC in some parts of the ASALs[10].Kenya is divided into seven agroecological zones (AEZs) with AEZs I – III classified as high potential areas and the others low potential areas. The AEZs, IV – VII are the ASALs where rangeland vegetation is located, pastoralism is a major economic activity and supports the bulk of Kenya's wildlife-based tourism.Kenya's current population is estimated to be 46,748,000 [11] living in both urban and rural areas in the 47 counties. Kenya's gross domestic product was Ksh 1.7 trillion for the 2014/2015 financial year [12] with the bulk of it from agriculture based activities.

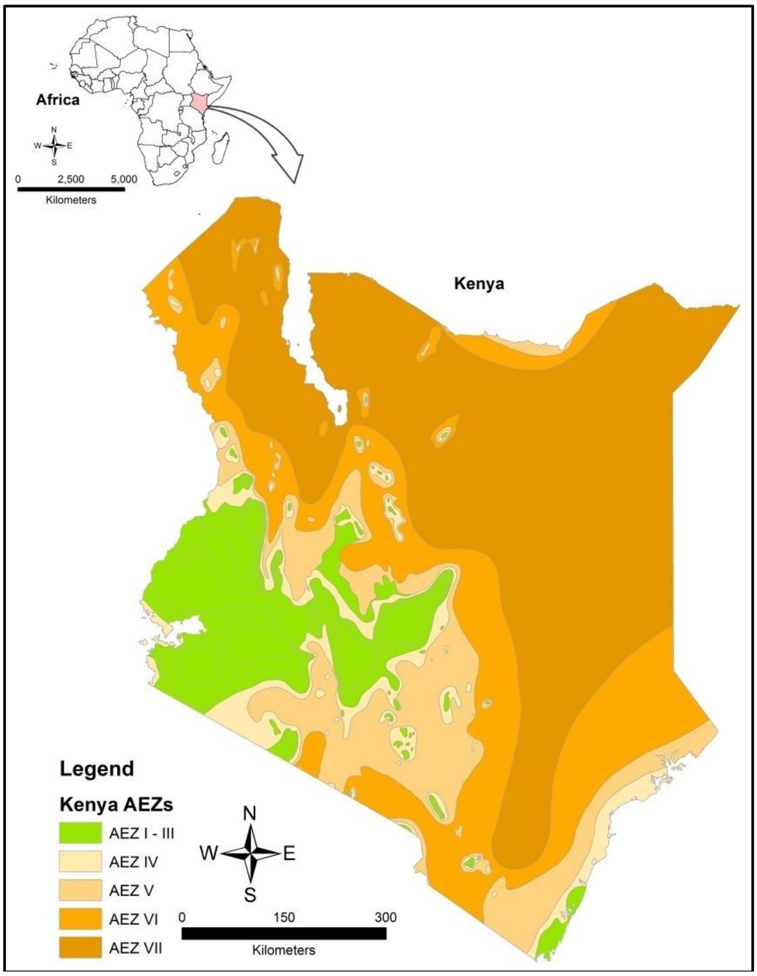

Figure1: Map of study area showing Kenya's Arid and Semi-Arid lands
(Source: Modified from data downloaded from ILRI)

2.2 Data acquisition

The vegetation data referred to as MODIS NDVI (Moderate Resolution Imaging Spectroradiometer Normalized Difference Vegetation Index) provided the vegetation phenology and sourced from the United States Geological Service (USGS) website www.earlywarning.usgs.gov, [13].They are multi-temporal images acquired by NASA Terra (AM-1) satellite's Moderate Resolution Imaging Spectroradiometer (MODIS) sensor. The datais derived from monitoring the world's vegetation with a spatial resolution of 250mwith varied temporal resolution. Kenya is grouped under the Eastern Africa countries and atotal of 1080 raster images were downloaded for the period covering 2001 – 2015 (15 years).The downloaded monthly data contained six dekadal datasets in 180 zipped folders.

2.3 Data processing and analysis

A spatial model wasdeveloped in ArcMap and used to process the data to generate mean monthly spatial data covering Kenya. Additionally, the resultantMODIS NDVI data were converted from stretch scale of 1 – 255 to the ratio scale of -1 – 1.Further extraction of the MODIS NDVI data to the specific area of interest (AOI) was carried out in ArcMAP(Fig. 2). The AOI was selected from Africover Kenya aggregate spatial data downloaded from United Nations website www.un-spider.org[14].The AOIidentification was guided by the Africover Project"Usable definition" document which constituted "Natural and Semi-natural Terrestrial Vegetation" and "Bare Areas"

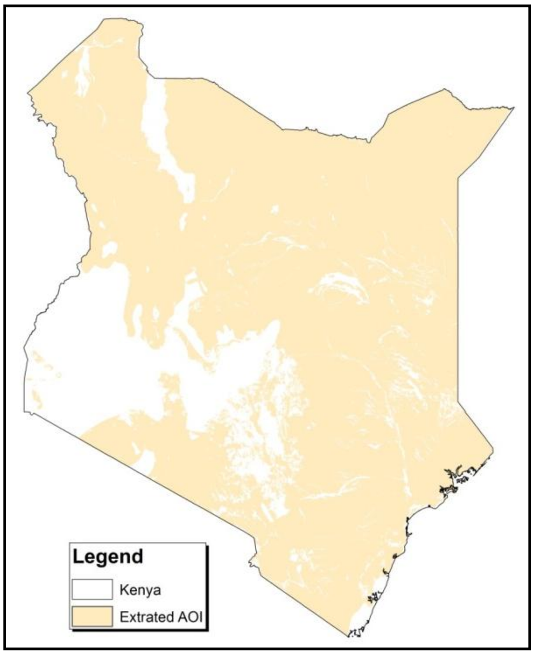

Figure2: The identified area of interest from Africover data

(Source: [14])

The rainfall dataset covering the study period was downloaded from the USGS website www.earlywarning.usgs.gov, [13] and processed in the same manner as MODIS NDVI. The rainfall data is called Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) and comprises monthly rainfall data. It has a resolution of 5,500m covering the whole world. Processing and analysis of this rainfall data was done in same way as the MODIS NDVI with an additional step of resampling to match MODIS NDVI data resolution.The spatial temporal analysis trend was performed using DIVA-GIS, kappa statistics (for both location and category) were generated in Map Comparison Kit while Geodaestablished the influence of rainfall on MODIS NDVI.

III. Results and Discussion

3.1 Rainfall spatio-temporal analysis

Therainfall distribution analysis was done for both monthly and annual time periods for the fifteen years (2001 - 2015). The monthly mean rainfall pattern (Fig.3)shows that the spatial distribution of mean monthly rainfall ranged from 0-389mm classified into five categories (0-80mm, 80-160mm, 160-240mm, 240-320mm and 320-400mm). The months of January, February and September mean rainfall ranged from 0-80mm with March, June – October and December receiving 0-160mm. The other months of April and November mean rainfall ranged between 0-320mm while the month of May recorded the highest value of 389mm.

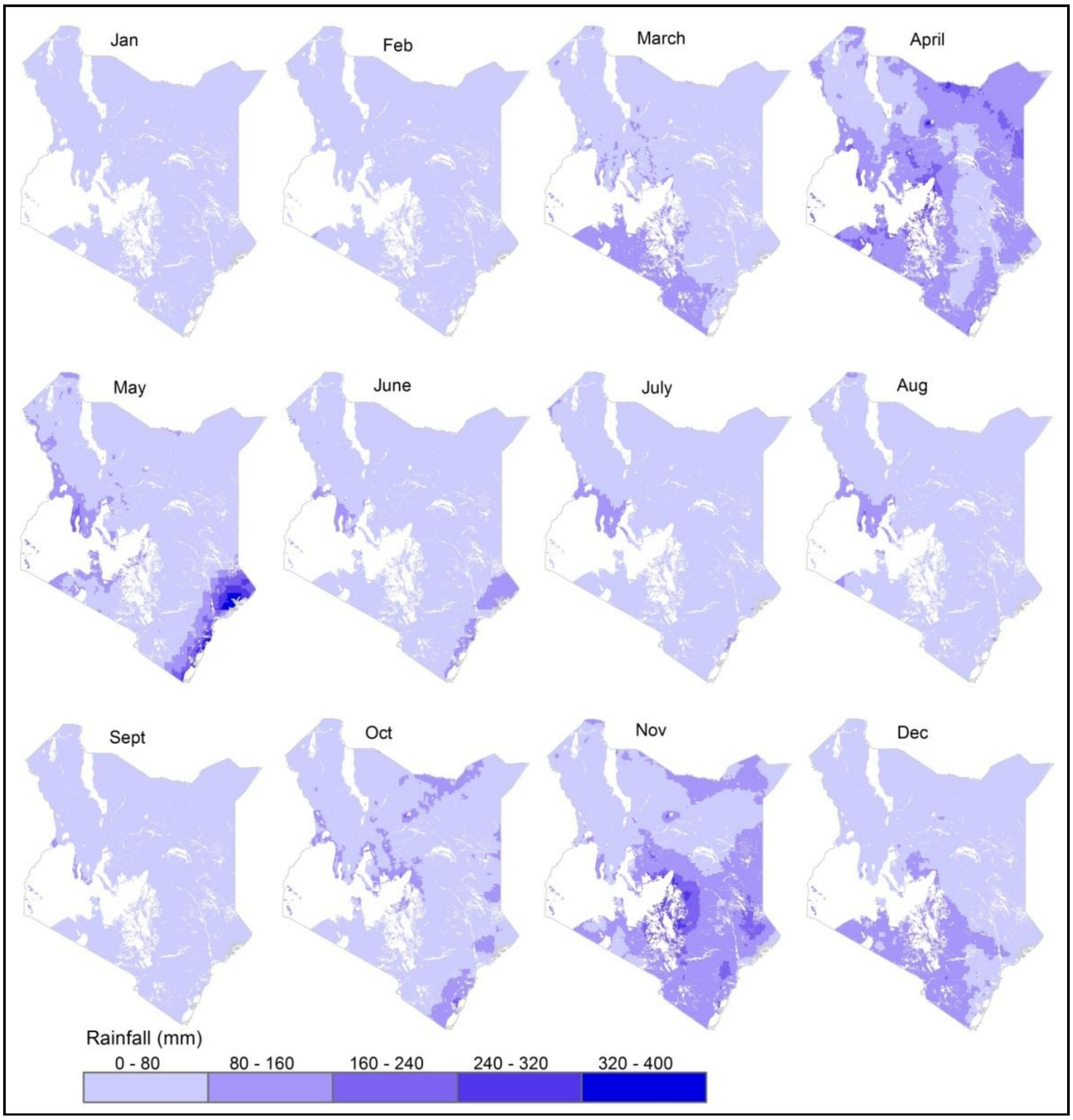

Figure3: Mean monthly rainfall (mm) distribution in the period under study in Kenya ASALs

The monthly rainfall trends (Fig.4) show both increasing and decreasing pattern with different magnitudes. The trend ranged between -15mm to 20mm in the months of January in central and May in the coastal regions respectively. The mean monthly rainfall trend by percent area (Table 1) show that January had the highest area of 92.3% (combined for 0 - - 15mm)under declining rainfall with rest of the country specifically in the north eastern and north coast regions indicating increasing rainfall trend.Other months with more than 50% of the area with declining rainfall trend though with different spatial distribution includeMay(68.9%), June (57.3%), August (52.5%) and December (56.1%).

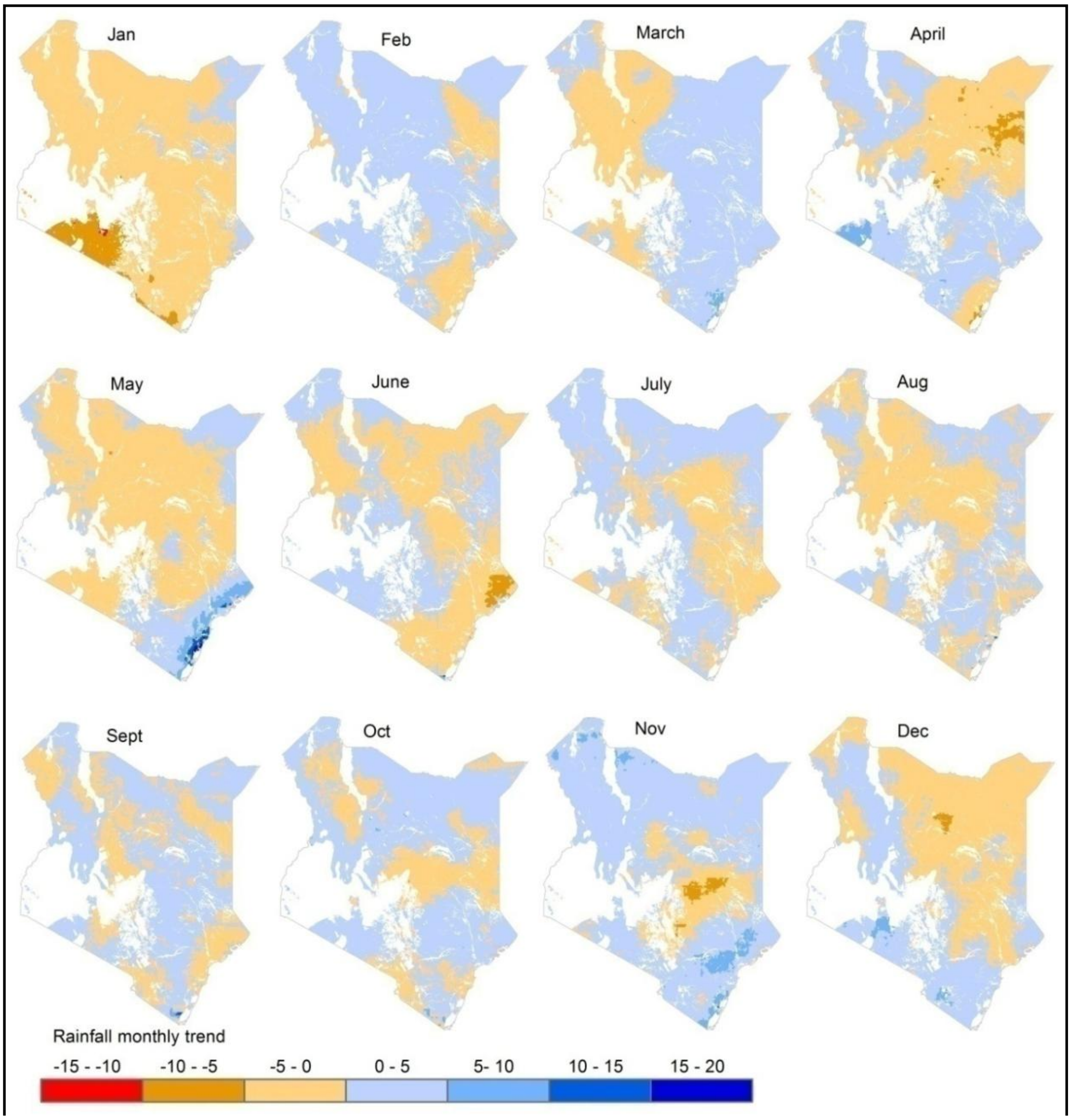

Figure4: The mean monthly spatial rainfall trend

The month of November had the highest area of 82.3% (combined for 0 – 20mm) followed by February with 81.6% (combined for 0 – 20mm) having positive rainfall trend. Other months of March (69.9%), April (57.0%), July (64.3%), September (65.9%) and October (70.9%) also had more than 50% of the area with rising rainfall trends.

Table 1: Monthly rainfall (mm) trend by percent area

Trend (mm)	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
-15 - - 10	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
-10 - -5	6.7	0.0	0.0	2.5	0.1	1.5	0.0	0.0	0.0	0.0	1.5	0.6
-5 – 0	84.5	18.4	30.1	40.4	68.9	55.8	35.7	52.5	34.1	29.1	16.2	55.5
0 – 5	8.7	81.6	69.3	55.5	27.3	42.6	64.3	47.4	65.7	70.7	78.3	42.9
5 – 10	0.0	0.0	0.6	1.5	3.0	0.1	0.0	0.1	0.1	0.2	3.9	1.0
10 – 15	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.1	0.0	0.0	0.0
15 – 20	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0

The similarity analysis used kappa statistics (K_{Loc} andK_{Histo}) presented on monthly basis for each year (Table 2) usingcounts of equal or more than the threshold of 0.50.The counts generated the percent number of years equal or more than the threshold. Based on this scale, the months were classified as either having or not having similarity.The months classified as similar were expressed as percentage for the entire period under study and plotted (Fig.5). The K_{Loc} statistic had a similarity pattern of zero (0) and low similarities between the months of January to April with a maximum of 100.00% from June to September. The similarity then reduces to less than 20.00% in October before becoming zero in December.The K_{Histo} maintained similarities of more than

60% with May, June, July, August and September having 100.00%. The high percent similarity observed indicate that the rainfall aspects of location and area covered are more or less the same from May – September. The other months of January – April and October – December have the lowest percent similarities a pointer to erratic and spatial shift rainfall patterns.

Table 2: Monthly rainfall Kappa statistics

Month	Kappa Stat	Year															
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Counts ≥0.50
Jan	K_{Loc}	0.45	0.59	0.29	0.17	0.65	0.32	0.60	0.32	0.52	0.33	0.40	0.12	0.63	0.18	0.31	5
	K_{Histo}	0.81	0.81	0.50	0.63	0.84	0.58	0.80	0.66	0.89	0.85	0.64	0.39	0.82	0.37	0.45	12
Feb	K_{Loc}	0.32	0.38	0.50	0.52	0.30	0.49	0.46	0.49	0.36	0.34	0.54	0.42	0.36	0.47	0.53	4
	K_{Histo}	0.75	0.58	0.75	0.74	0.67	0.88	0.78	0.62	0.72	0.65	0.76	0.80	0.66	0.83	0.76	15
March	K_{Loc}	0.33	0.31	0.22	0.15	0.09	0.35	0.19	0.39	-0.41	-0.10	-0.01	-0.42	0.07	0.16	0.00	0
	K_{Histo}	0.98	0.73	0.72	0.64	0.51	0.58	0.68	0.66	0.28	0.35	0.58	0.32	0.42	0.77	0.73	11
April	K_{Loc}	0.37	0.22	0.10	0.32	0.24	0.43	0.14	0.35	0.10	0.31	-0.06	0.10	0.05	0.14	0.08	0
	K_{Histo}	0.84	0.80	0.70	0.88	0.68	0.72	0.77	0.75	0.43	0.78	0.29	0.78	0.60	0.72	0.64	13
May	K_{Loc}	0.48	0.54	0.47	0.41	0.50	0.61	0.56	0.53	0.68	0.59	0.58	0.51	0.69	0.52	0.62	12
	K_{Histo}	0.53	0.77	0.74	0.72	0.77	0.91	0.93	0.51	0.89	0.81	0.72	0.86	0.72	0.80	0.85	15
June	K_{Loc}	0.63	0.63	0.69	0.58	0.72	0.73	0.54	0.64	0.64	0.74	0.61	0.64	0.68	0.64	0.68	15
	K_{Histo}	0.91	0.94	0.92	0.84	0.92	0.88	0.86	0.93	0.89	0.96	0.93	0.92	0.93	0.95	0.94	15
July	K_{Loc}	0.77	0.57	0.82	0.73	0.69	0.75	0.52	0.70	0.59	0.64	0.76	0.67	0.76	0.74	0.57	15
	K_{Histo}	0.94	0.92	0.83	0.83	0.96	0.86	0.85	0.86	0.75	0.93	0.86	0.86	0.94	0.97	0.94	15
Aug	K_{Loc}	0.76	0.62	0.69	0.75	0.71	0.59	0.61	0.77	0.67	0.77	0.68	0.68	0.73	0.71	0.64	15
	K_{Histo}	0.90	0.94	0.86	0.91	0.90	0.90	0.86	0.88	0.84	0.92	0.92	0.88	0.91	0.89	0.85	15
Sept	K_{Loc}	0.70	0.62	0.68	0.64	0.67	0.59	0.57	0.74	0.67	0.74	0.70	0.70	0.64	0.72	0.67	15
	K_{Histo}	0.84	0.90	0.86	0.90	0.86	0.92	0.82	0.89	0.75	0.94	0.85	0.87	0.78	0.91	0.85	15
Oct	K_{Loc}	0.25	0.48	0.37	0.56	0.33	0.29	0.46	0.37	0.44	0.34	0.13	0.45	0.42	0.33	0.54	2
	K_{Histo}	0.49	0.85	0.66	0.86	0.50	0.67	0.78	0.72	0.69	0.53	0.56	0.89	0.64	0.61	0.94	14
Nov	K_{Loc}	0.42	0.40	0.39	0.31	-0.14	0.04	0.38	-0.21	-0.01	0.13	0.04	0.44	0.35	0.50	0.29	1
	K_{Histo}	0.75	0.71	0.87	0.88	0.52	0.55	0.80	0.18	0.46	0.64	0.44	0.79	0.94	0.85	0.68	12
Dec	K_{Loc}	0.23	-0.04	0.32	0.39	-0.63	-0.09	0.09	-0.42	0.19	-0.14	0.29	0.25	0.26	0.35	0.38	0
	K_{Histo}	0.64	0.54	0.71	0.79	0.29	0.59	0.63	0.39	0.66	0.57	0.63	0.72	0.59	0.76	0.71	13

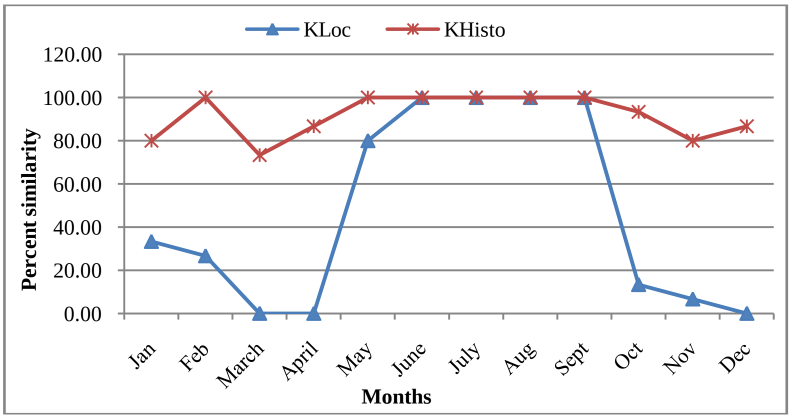

Figure5: Mean monthly rainfall K_{Loc} and K_{Histo}percent similarity kappa statistics

The annual spatial and temporal distribution patterns of rainfall (Fig.6)ranged from 16-2259mm. In general the rainfall distribution was higher in the central, southern and coastal areas of the country. The northern, north eastern and eastern regions recorded low mean rainfall. The wettest years were 2002 and 2006 with maximums of 2000 – 2500mm of rain while 2008 and 2009 were the driest years in the study period with maximum rainfall not exceeding 1500mm. The mean rainfall of the years 2005, 2008 and 2009 ranged from 0-1500mm whereas it was between 0-2000mm in the years 2001, 2002, 2003, 2004, 2007, 2011, 2014 and 2015. The years whose maximum mean rainfalls were more than 2000mm are 2006, 2010, 2012 and 2013 though this covered minimal areas covering the coastal and central regions of the country.

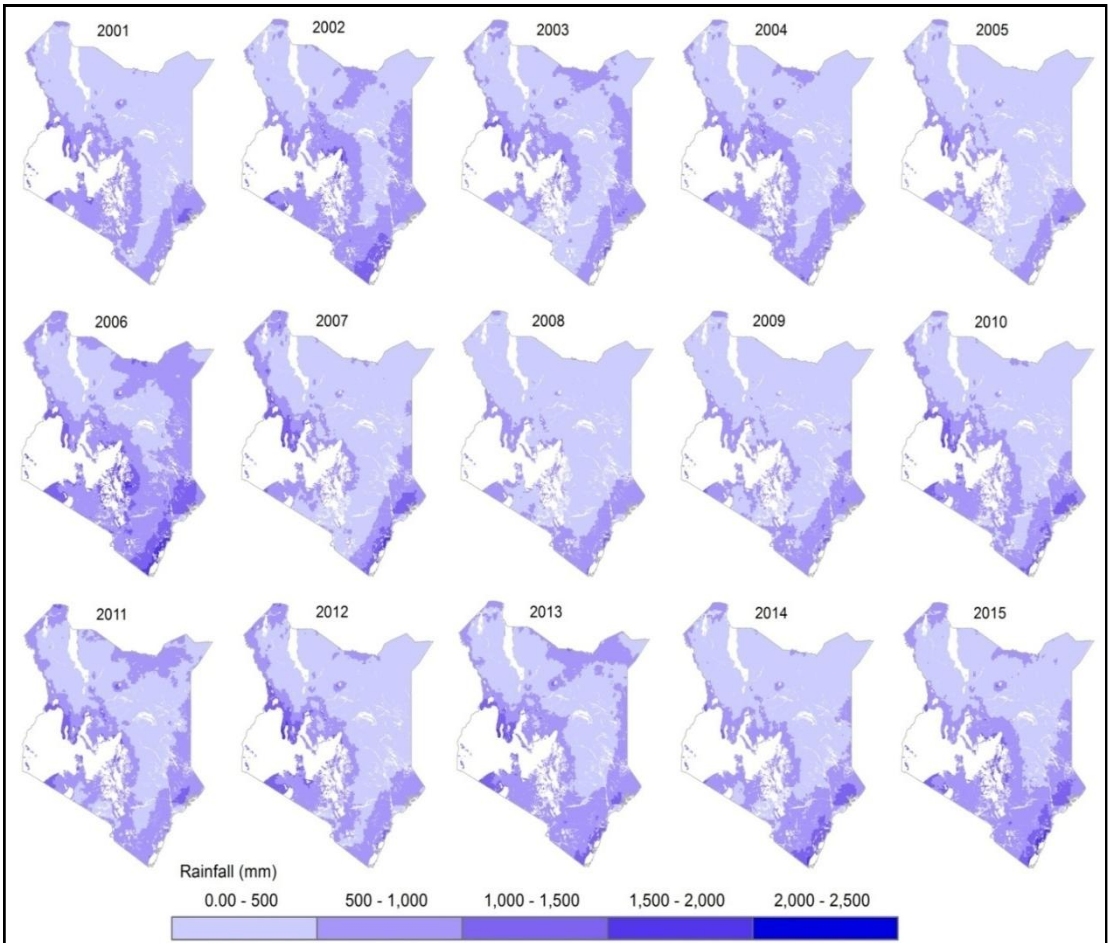

Figure6: Mean annual rainfall spatial distribution

The annual rainfall spatial trend analysis based on CHIRPS data for the 15 years illustrate that the entire country experienced a negative trend ranging from -6 – 0mm (Fig.7). In the north west, northern and north eastern sectionswhich constitute about 60.8% by area, the rainfall trend rangedfrom -2 – 0mm. The other regions of central, southern and coastal areas decreased by -4 - -2mm and represented 37.4% of Kenya's area. The areas with the most reduced rainfall trend by -6 –4mm were scattered in the central, southern and coastal regions covering 1.8% of the area.

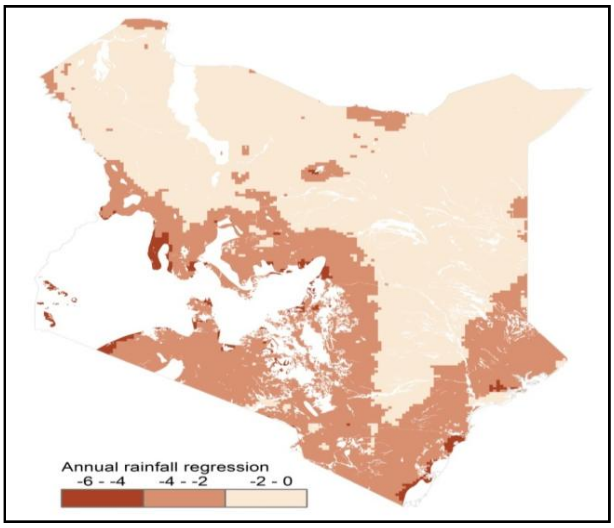

Figure7: Annual rainfall trend 2001 to 2015

The annual rainfallK_{Loc} and K_{Histo} kappa statistics percent similaritiesare presented in Fig.8. The K_{Loc}percent similarity ranged between 33.33% in 2001 to 58.33% in 2015, with the other years ranging between 40.00 – 50.00%. The K_{Histo} values were all more than 75.00% with the least in 2009 and the highest in 2002, 2004, 2006 and 2007 at 100.00%.

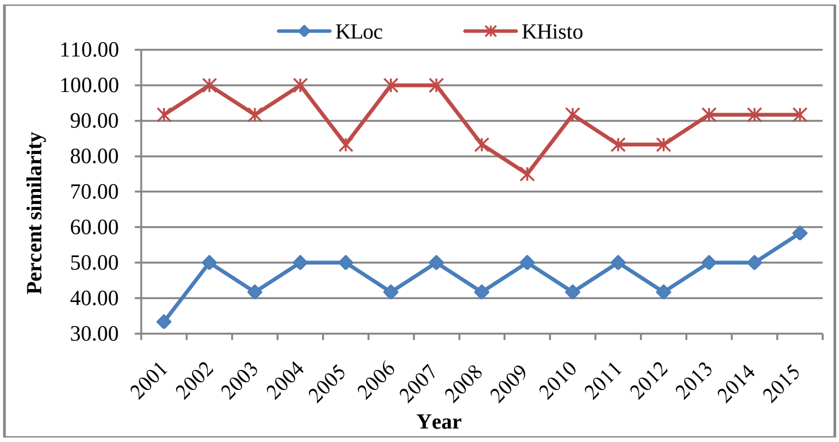

Figure8: The annual rainfall K_{Loc} and K_{Histo}percent similarity kappa statistics

3.2 MODIS NDVI spatio-temporal analysis

The MODIS NDVI trend analysis was done at spatio-temporal scale on both monthly and annual basis for the period under study (2001 - 2015). The MODIS NDVI is the mean biomass production over the period at pixel value presented as mean for both monthly and yearly basis. The monthly MODIS NDVI distribution (Fig.9) is the spatial pattern. The MODIS NDVI pattern shows that most of the coastal, central and southern regions have higher values compared to the northern and north eastern regions. This is an indication that there is a spatial variation of vegetation distribution in Kenya. The lower the MODIS NDVIis, the poorer the status of vegetation ina region.

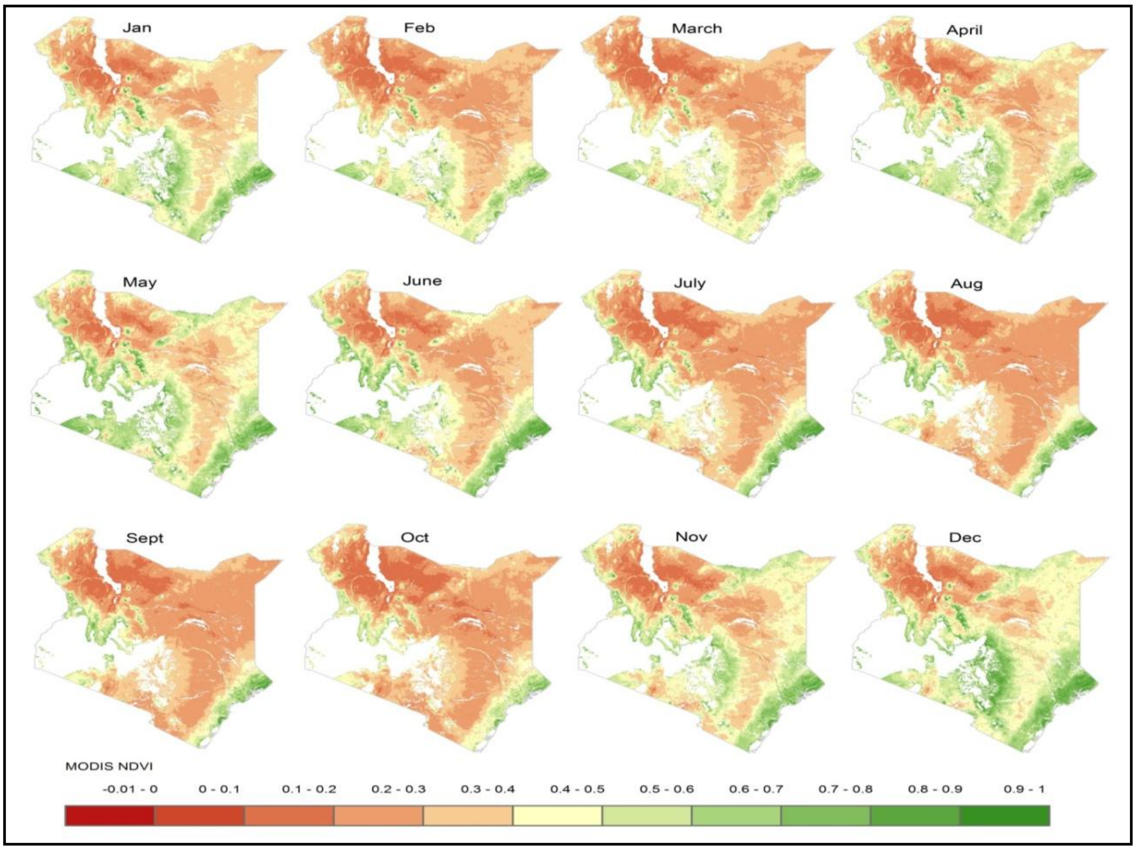

Figure9: Mean monthly MODIS NDVI

The monthly MODIS NDVI trend analysis showed both increasing and decreasing trends of between -0.0620677 – 0.060(Fig.10) differing with the months. The highest negative trend of -0.0620677 was recorded in the month of November while 0.0559023 was the highest positive trend in October. The month of December recorded extreme MODIS NDVI values in both directions which ranged from -0.0588346 to 0.0572932.

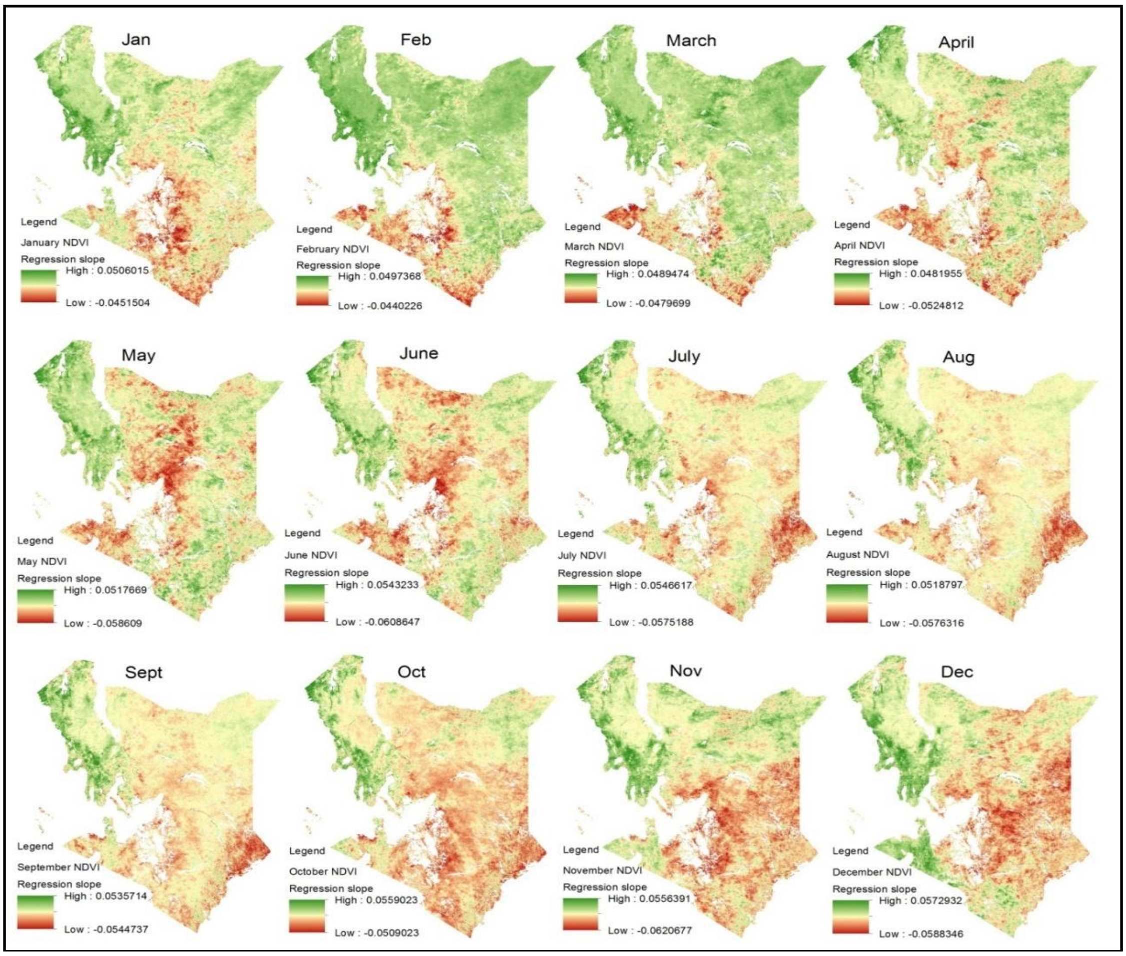

Figure10: MODIS NDVI monthly trend

The monthly MODIS NDVI data was converted into binary data showing decreasing (-0.065 - 0) and increasing (0 – 0.060) trends. The trends by percent area in each month were summarised and presented Table 3, with the overall picture indicating a net decline in rangeland vegetation. The percent areas under decreasing trend ranged from 42.35% (March) – 70.97% (June). The months with decreasing trend in percent areas under are March (42.35%), April (48.83%) and November (48.80%). The rest of the months have more than 50% to a maximum of 70.97% in June. The months with increasing percent area trends with more than 50% were in March (57.65%), April (56.17%) and November (51.20%) whereas the other months were between 29.07% (June) – 49.02% (October). This seasonal variation in MODIS NDVI trends indicates that there is a net loss of vegetation in the country though at different locations and magnitudes.

Table 3: Monthly MODIS NDVI trend by percent area

	Months											
Trend	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
-0.065–0	52.26	68.83	42.35	43.83	67.76	70.97	69.19	67.74	59.70	50.98	48.80	51.13
0 – 0.060	47.74	31.17	57.65	56.17	32.24	29.03	30.81	32.26	40.30	49.02	51.20	48.87

The spatial depiction of the monthly MODIS NDVI trends is captured in (Fig. 11). In all the months, the north western region of the country had positive trends. Other months of January – April and June – December showed increasing trends in the northern and north-eastern tip. The majority of the southern parts had a decreasing trend with exception of some few areas in south western parts in the months of January and September – December.

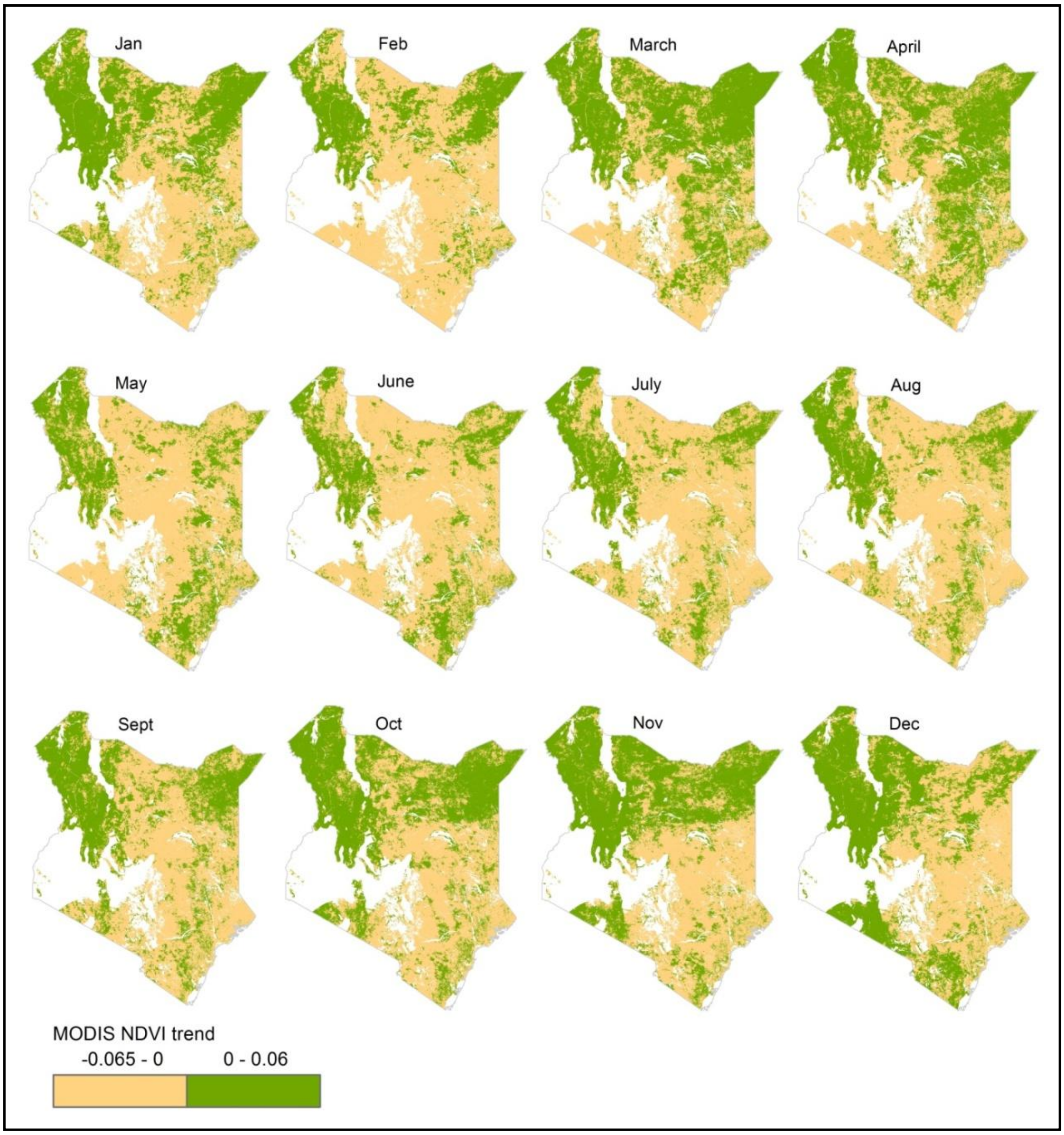

Figure11: Binary monthly MODIS NDVI spatial temporal trend

The monthly MODIS NDVI similarity analysis used Kappa statistics (K_{Loc} and K_{Histo}) presented on monthly basis for each year (Table 4). The individual monthly spatial data were compared against their means using the scale of “Not Similar” (0.00 – 0.49) and “Similar” (0.50 – 1.00). In the period under study, the counts for each month with K_{Loc} and K_{Histo}≥0.50ranged from 0 – 15 (0 – 100%). By applying the earlier described scale, the months were classified as either having or not having similarity and those similar expressed as percentage then plotted (Fig.12). The K_{Loc}percent similarity fluctuated between 86.67 - 100.00% from January – September before reducing to 66.68% in October, then 0.00% in November before increasing to 73.33% in December. The K_{Histo} statistic had similarity pattern of 100.00% throughout except in the moths of January and March which were also more than 80.00%. These monthly percent similarity patterns indicate stability of both location and sizes of areas of rangeland vegetation. However, in the month of November the percent similarity was 0.00%, an indication that the rangeland vegetation shift in location was very high though the sizes of the areas under the different categories remained the same.

Table 4: The MODIS NDVI kappa statistics of K_{Loc} and K_{Histo}

Months	Kappa	Year															
		2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	Counts ≥0.50
Jan	K_{Loc}	0.75	0.72	0.58	0.66	0.74	0.45	0.07	0.78	0.62	0.71	0.80	0.55	0.73	0.78	0.76	13
	K_{Histo}	0.67	0.85	0.79	0.92	0.86	0.65	0.47	0.85	0.74	0.88	0.82	0.75	0.85	0.86	0.94	14
Feb	K_{loc}	0.77	0.81	0.74	0.71	0.79	0.67	0.39	0.76	0.73	0.71	0.75	0.73	0.80	0.80	0.73	14
	K_{Histo}	0.75	0.84	0.91	0.93	0.96	0.71	0.65	0.92	0.82	0.92	0.72	0.87	0.88	0.91	0.76	15
March	K_{loc}	0.81	0.77	0.82	0.82	0.83	0.80	0.67	0.84	0.72	0.60	0.80	0.78	0.77	0.73	0.73	15
	K_{Histo}	0.84	0.84	0.94	0.90	0.93	0.82	0.31	0.89	0.82	0.74	0.80	0.85	0.97	0.91	0.36	13
April	K_{loc}	0.66	0.72	0.72	0.72	0.72	0.75	0.73	0.72	0.51	0.45	0.57	0.70	0.51	0.65	0.59	14
	K_{Histo}	0.82	0.87	0.90	0.81	0.78	0.84	0.88	0.83	0.68	0.69	0.66	0.80	0.69	0.90	0.92	15
May	K_{loc}	0.66	0.55	0.55	0.64	0.66	0.70	0.68	0.59	0.44	0.62	0.46	0.52	0.54	0.59	0.65	13
	K_{Histo}	0.83	0.77	0.75	0.85	0.83	0.78	0.79	0.86	0.68	0.83	0.61	0.82	0.78	0.83	0.88	15
June	K_{loc}	0.71	0.59	0.47	0.73	0.60	0.73	0.73	0.66	0.72	0.69	0.70	0.59	0.72	0.72	0.72	14
	K_{Histo}	0.73	0.82	0.74	0.94	0.92	0.88	0.87	0.92	0.75	0.93	0.71	0.87	0.93	0.84	0.94	15
July	K_{loc}	0.79	0.72	0.66	0.75	0.71	0.80	0.67	0.75	0.79	0.74	0.77	0.66	0.70	0.82	0.80	15
	K_{Histo}	0.78	0.85	0.83	0.94	0.96	0.88	0.88	0.95	0.75	0.97	0.75	0.89	0.98	0.87	0.91	15
Aug	K_{loc}	0.81	0.72	0.76	0.81	0.83	0.82	0.64	0.82	0.75	0.78	0.80	0.68	0.72	0.85	0.83	15
	K_{Histo}	0.91	0.93	0.89	0.91	0.88	0.89	0.86	0.90	0.66	0.98	0.79	0.93	0.97	0.88	0.87	15
Sept	K_{loc}	0.81	0.71	0.80	0.80	0.85	0.78	0.70	0.81	0.77	0.82	0.75	0.69	0.81	0.78	0.79	15
	K_{Histo}	0.95	0.90	0.87	0.96	0.93	0.97	0.76	0.96	0.72	0.94	0.88	0.94	0.90	0.95	0.91	15
Oct	K_{loc}	0.63	0.39	0.57	0.54	0.69	0.49	0.39	0.54	0.51	0.70	0.41	0.49	0.66	0.55	0.56	10
	K_{Histo}	0.91	0.86	0.91	0.87	0.87	0.86	0.82	0.90	0.93	0.90	0.75	0.89	0.92	0.91	0.98	15
Nov	K_{loc}	0.39	0.37	0.36	0.41	0.21	0.35	0.48	0.37	0.35	0.26	0.25	0.39	0.41	0.42	0.47	0
	K_{Histo}	0.84	0.82	0.78	0.86	0.65	0.77	0.88	0.91	0.86	0.68	0.70	0.85	0.91	0.83	0.91	15
Dec	K_{loc}	0.61	0.62	0.59	0.58	0.39	0.25	0.64	0.66	0.64	0.40	0.29	0.66	0.63	0.62	0.59	11
	K_{Histo}	0.86	0.84	0.85	0.87	0.64	0.56	0.84	0.84	0.82	0.69	0.56	0.88	0.94	0.87	0.89	15

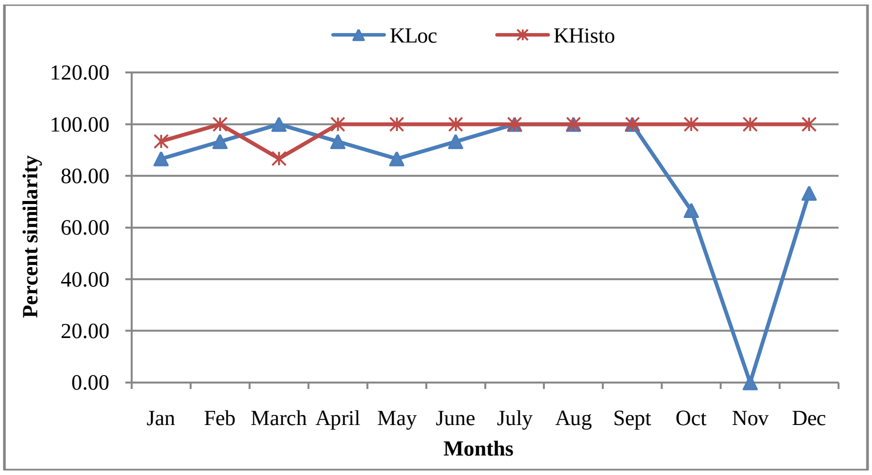

Figure12: Mean monthly MODIS NDVI K_{Loc} and K_{Histo}percent similarity kappa statistics

The annual MODIS NDVI spatial distribution (Fig. 13)patterns are more or less the same as monthly and ranged between -0.01 - 1. The regions with high MODIS NDVI are coastal, southern and central with the north eastern and northern parts having low values. However, there are patches of areas with high MODIS NDVI in the regions with predominantly low values.

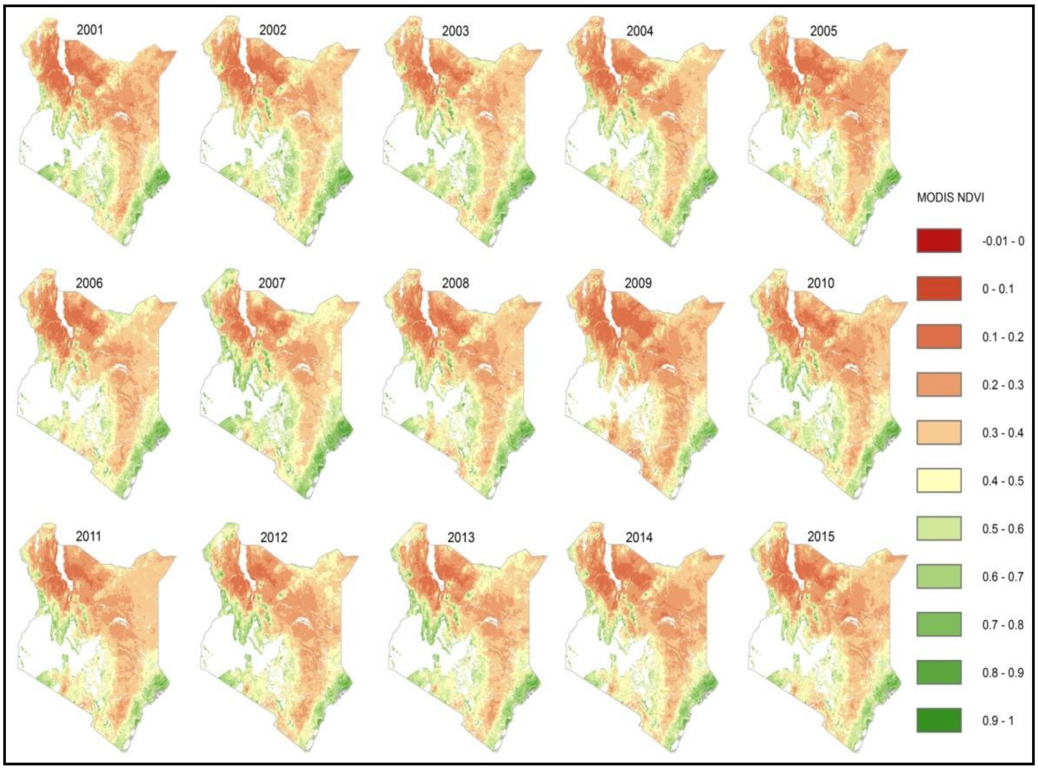

Figure13: Mean annual MODIS NDVI

The annual MODIS NDVI analysis also indicated that the country experienced both negative (decrease) and positive (increase) trends for different regions ranging from between -0.0495927 – 0.0468138. The north western area and the north eastern tip of the country had an increasing MODIS NDVI trend (Fig.14). The areas with decreasing MODIS NDVI trend was more in the eastern, coastal, southern parts and also scattered all over the country.The binary analysis(Fig.15)indicated that 38.01 % of the country experienced a positive trend with the rest, 61.99% having negative trend.

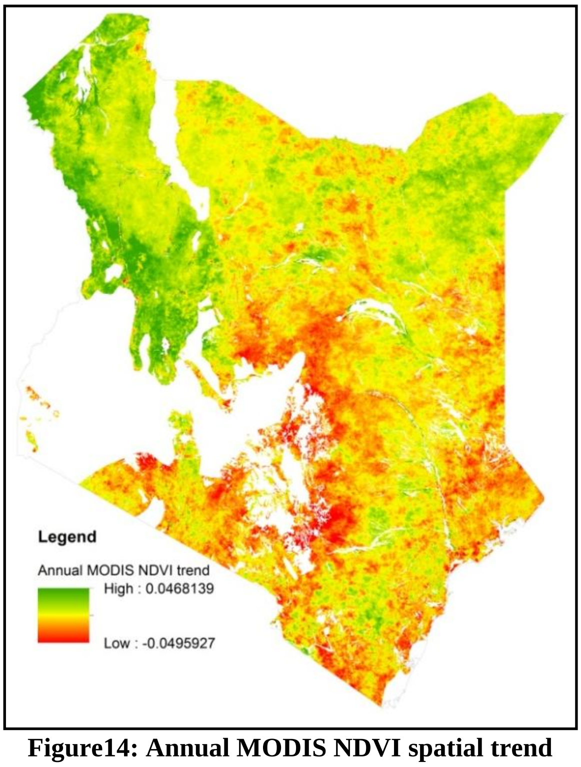

Figure14: Annual MODIS NDVI spatial trend

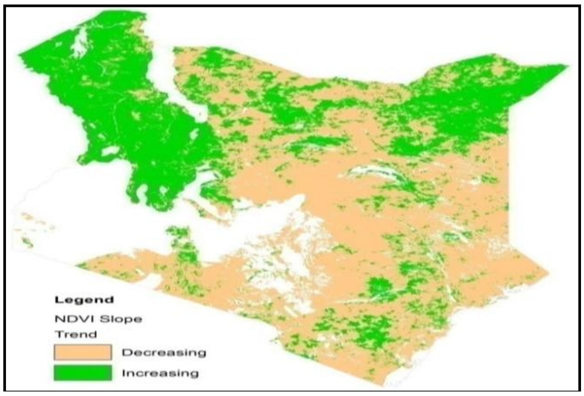

Figure15: Annual MODIS NDVI binary spatial trend

The annual MODIS NDVI percent similarities for both K_{Loc} and K_{Histo}kappa statistics were all more than 60.00% (Fig.16). The K_{Loc}rangedfrom66.67% for years 2006, 2007 and 2011 to 91.67% in 2001, 2004, 2008, 2013, 2014 and 2015. The other years' percent similarities are within theselow and high ranges. These values point out that both the spatial and areas of the rangeland vegetation are stable an indication of consistency.

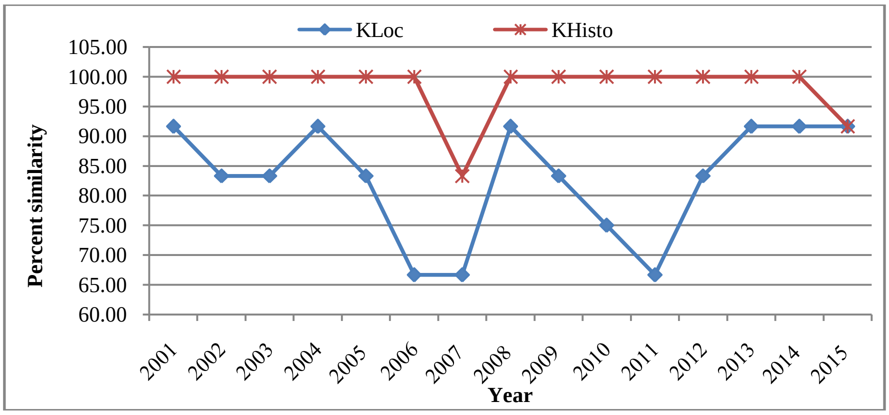

Figure16: The annual MODIS NDVI K_{Loc} and K_{Histo}percentsimilarity kappa statistics

3.3 Rainfall and MODIS NDVI regression analysis

The relationship between annual mean rainfall and annual mean MODIS NDVI for the study period was sought through linear regression analysis in Geoda software. The results (Table 5) summarises the linear regression analysis for all the individual years and the mean of the fifteen years under study. All the results indicate that there wasa significant relationship between the rainfall and MODIS NDVI, p = 0.000. The coefficient of determination ranged between 0.541 in the year 2002and 0.763 in 2006for the individual years and was 0.617 for the fifteen years mean (2001 - 2015). These results indicate that within the fifteen years (2001 - 2015), the vegetation (MODIS NDVI) was dependent on the rainfall.

Table 5: Annual and 15 year mean spatial regression between rainfall and MODIS NDVI

Year	p-value	T	r^2(adjusted)	Equation
2001	0.000	246.381	0.763	NDVI = 0.155 + 0.00052(Rain)
2002	0.000	149.186	0.541	NDVI = 0.163 + 0.00050(Rain)
2003	0.000	214.683	0.709	NDVI = 0.150 + 0.00054 (Rain)
2004	0.000	183.537	0.641	NDVI = 0.211 + 0.00053(Rain)
2005	0.000	190.746	0.658	NDVI = 0.133 + 0.00034 (Rain)
2006	0.000	162.749	0.584	NDVI = 0.217 + 0.00037(Rain)
2007	0.000	209.197	0.699	NDVI = 0.218 + 0.00062(Rain)
2008	0.000	212.610	0.705	NDVI = 0.171 + 0.00055(Rain)
2009	0.000	179.799	0.631	NDVI = 0.162 + 0.00037(Rain)
2010	0.000	184.350	0.643	NDVI = 0.137 + 0.00049 (Rain)
2011	0.000	165.596	0.592	NDVI = 0.204 + 0.00036 (Rain)
2012	0.000	173.842	0.616	NDVI = 0.161 + 0.00042 (Rain)
2013	0.000	158.549	0.571	NDVI = 0.210 + 0.00041(Rain)
2014	0.000	186.222	0.648	NDVI = 0.159 + 0.00039 (Rain)
2015	0.000	227.553	0.733	NDVI = 0.143 + 0.00049(Rain)
Mean (15yrs)	0.000	174.323	0.617	NDVI = 0.149 + 0.00042(Rain)

Climate change and its impacts have been widely studied though there are still many gaps of knowledge due to scientific uncertainties. However, analysis of the past climatic variables trends such as rainfall can give evidence on the tendency and magnitude of variability within a given period. Along with the analysis of rainfall is how the trend has influenced vegetation, a critical support of the major economic activity in Kenya. Kenya's land area is divided into AEZs each with distinct climatic characteristics. The agroecological zones IV – VI, which is classified as the arid and semi-arid lands (ASALs) are characterised by low and highly variable rainfalls of different amounts.

The current study showed that the spatial and temporal distribution of vegetation (MODIS NDVI) is dependent on climate (rainfall and temperature)within the fifteen years (2001 – 2015) of study. The rainfall trend analysis by [15] reported that south eastern region Kenya is slowly registering a shift in the seasonal rainfall pattern. Thisshift in rainfall pattern is supported by a study of rainfall variability in arid and semi-arid lands of Kenya by[16] who concluded that the September – December season is becoming more reliable than the March-May season. Further, analysis by [17] pointed out that annual rainfall was below the long-term average during 2008, 2009 and 2010 and in the first half of 2011. Moreover, [17] synthesis of monthly rainfall made the following conclusions; the mean monthly rainfall in 2008 was below average 67% of the time; in 2009, the number of months showing less rainfall than the long-term monthly average increased to 75% of the time; In 2010, the number of rainfall deficit months decreased to 62% of the time; and in the first half of 2011, it was72% of the time.[18], made a number of conclusions toowith respectto Kenya climate trend analysis study including but not limited to a 100mm decline in Kenya's central region long rains since mid-1970s and a drying tendency.

The rainfall variability is as a result of both natural and man-induced activities [19]. Howevermany studies have documented unusual variability in seasonal and annual rainfall patterns in aspects of location and amounts[5], [1]. The observed variability in the rainfall patterns follows that the vegetation will also change in more or less the same direction and magnitude. Studies on the causes of variations in vegetation have shown that climatic factors, particularly precipitation and temperature, significantly influence vegetation dynamics [2]; [20]. [21]reported a strong link between rainfall distribution in a semi-arid savannah grassland and inter-annual variation in plants species composition in West Africa region. In 2005-2006 Kenya faced a prolonged dry spell due to failure of rain, particularly the October to December short rains in 2005 [10] which affected 3.5 million people mainly from the pastoralist region. Other examples of negative climatic impact studies are long-term decrease in precipitation linked to anthropogenic climate change [22] in Sahel region and extreme drought in North Africa [23] is linked to severe mortality of Atlas cedar (Cedrusatlantica) from Morocco to Algeria.These vegetation dynamics resulting from climate influence at regional levels are best analysed using MODIS NDVI data.

The use of MODIS NDVI to quantify vegetation change is now a norm in many vegetation related studies by many researchers.The relationship between rainfall and MODIS NDVI is linear and normally sought through regression analysis.The analysis of Kenya's rainfall and MODIS NDVI relationship established significant and strong relationship for all the years a situation also concluded by other researchers such as [16],[24],[25]. Further, [26] demonstrated that both rainfall and MODIS NDVI are useful in identifying hot spots and degraded areas.

IV. Conclusion

The spatial and temporal trends of climate (rainfall)and MODIS NDVI from 2001 – 2015analysis was based on spatial data and made the following conclusions: the monthly rainfall trends were both decreased and increased ranging from -15 – 20mm in different places; the rains were more or less the same from May – September while spatial shifts occurred in the months of January – April and October – Decemberalthough the sizes of areas under different rainfall regimes were similar;the annual rainfall indicated a reducing trendof -6 – 0mm in the entire country; there were spatial shifts in rainfall patterns in some years although no shifts were detected in the 15 years period mean;the sizes of the categories receiving different rainfall amounts did not change in the entire period under study; the monthly MODIS NDVI trend both increased and decreased in different parts of the country at the range of -0.065 - 0.060; annually,the trends were not different and did not shift spatially; and the dependence of MODIS NDVI on rainfall was significant in both monthly and annual time periods.

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