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Full Length Research Paper

Drought monitoring in Kenya: A case of Tana River County

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Standardized Precipitation Index (SPI) is used to assess past, present and projected drought conditions while Mann Kendall trend test and coefficient of variability is used for trend analysis. Observed data from National Meteorological and Hydrological Centre in Kenya and simulated data based on Special Report on Emission Scenarios (SRES) A1B and A2 from Providing Region Climate for Impact Studies (PRECIS) Model and Representative Concentration Pathways (RCP) RCP 4.5 Wm^{-2} and RCP 6.0 Wm^{-2} from Commonwealth Scientific and Industrial Research Organization (CSIRO) were used. Observed datasets (rainfall and temperature), projected temperature (A1B and A2, RCP 4.5 Wm^{-2} and RCP 6.0 Wm^{-2}) and rainfall (A2 and RCP 6.0 Wm^{-2}) all showed monotonic trend. A1B scenario had no significant trend. Decreasing patterns observed from SPI values based on observations showed increase in dry conditions. Although projected rainfall showed a decreasing trend, the frequency and magnitude of drought events increased under all future scenarios. Risk analysis based on observed data showed that north and central region of Tana River county were susceptible to intense droughts conditions and projected shift northwards under all scenarios. The susceptibility of the region to drought conditions is thus expected to increase conflicts due to limited water resources, pasture and food insecurity in the region and thus limit achievement of Kenya's long term development envisioned in the Vision 2030.

Key words: Climate change, drought, livestock production, scenarios, semi arid.

INTRODUCTION

Climate exerts a significant control on the day-to-day socio-economic development (IPCC, 2007). Climate extremes such as droughts and floods are strongly influenced by both small- and large-scale weather patterns, modes of variability, thermodynamic processes, land–atmosphere feedbacks and antecedent conditions (Ngaina and Mutai, 2013; IPCC, 2013). Notably, numerous challenges exist in assessing changes in climate extremes not only due to intrinsically rare nature of these events, but because they invariably happen in conjunction with disruptive conditions especially in key sectors such as agriculture in many developing countries whose vulnerability to climate change has been exacerbated by its weak adaptive capacity (IPCC, 2007, 2013).

In Kenya, agricultural sector contributed 36.6% of Gross Domestic Product (GDP) in the period of 1964-1974, 33.2% in 1974-1979, 29.8% in 1980-1989, 26.5% in 1990-1995 and 24.5% in 1996-2000 (FAO, 2005). FAO's (2005) report indicate that livestock sector accounted for 90% of employment and more than 95% of family incomes in Arid and Semi Arid Lands (ASALs). Vulnerabilities of communities to impacts of climate

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change is exacerbated by the highest incidence of poverty (about 65%) and very low access to basic social services such as infrastructure and education facilities. Notably, this increased fragility of the ASALs has become increasingly difficult for the livestock sector to sustain production to cope with increased demand for products. FAO estimated that the annual growth rate of livestock production (value of animals) in Kenya declined from 3.5% in 1980-1990 to -1.3% in 1990-2000 and was attributed to factors such as inadequate and inefficient infrastructure, lack of farm credit and high costs of farm inputs, inappropriate technology and inadequate funding for research and extension (FAO, 2005).

Climate can affect livestock both directly and indirectly; climate shocks can have devastating effects among the poor (Mcpeak, 2006). Direct effects from air temperature, humidity, wind speed and other climate factors influence animal performance: growth, milk production, wool production and reproduction (Houghton et al., 2001). Indirect effects include climatic influences on the quantity and quality of feedstuffs such as pasture, forage, grain and the severity and distribution of livestock diseases and parasites (Seo and Mendelsohn, 2006). A decrease in mean annual precipitation may be expected to have a negative impact on the grassland but a temperature increase could be expected to have a positive effect on the amount of grassland as forests shift to grassland, which may lead to increased livestock products.

In planning for drought mitigation, there has been a shift from disaster management to drought risk management, which is quite difficult when the behavior and characteristic of droughts and expected losses are not predictable. Understanding the effects of climate change on livestock productivity is crucial to mitigate the adverse impact on the gains from other efforts. Therefore, the study sought to assess the trend of the past, present and future rainfall and temperature and severity of drought conditions using Mann Kendall test, coefficient of variability and Standardized Precipitation Index (SPI) over Tana River County in Kenya.

Area of study

Tana River County lies between the equator and 3°S, and longitudes 38° 30’ E and 40° 15’ E in the coastal low land as shown in Figure 1. Tana River County covers a total area of 38,782 km^2. The major physical feature is an undulating plain which is interrupted in a few places by low hills. The altitude ranges from sea level to 200 m. It is traversed by river Tana from the head waters on the eastern slopes of Mt Kenya to the Indian Ocean in the south-east. A large flood plain formed in the county due to seasonal flooding of Tana River forms the backbone of the district and varies in width between 2 and 4 km in some areas. It provides vast areas of land for cultivation and dry season grazing. The hinterland has seasonal streams (or lagas) that support wet season grazing. As the Tana River enters the Indian Ocean, it forms a delta that covers the lower part of Garsen division and the entire Kipini division.

The county receives low and erratic convectional rainfall. The mean annual rainfall varies between 300 and 500 mm. Rainfall is bimodal; the long rains come in April and May and the short rains in October and November. November is the wettest month. Due to the convectional type of rainfall, the coastline is wetter than the hinterland, with up to 1250 mm of rain annually. The mean annual temperature is about 30°C. February, March, September and October are the hottest months of the year, when temperatures rise beyond 35°C (GoK, 1997).

DATA AND METHODOLOGY

This study used both observed and model output. The observed rainfall and temperature ranged from 1961 to 2008 and was sought from the Kenya Meteorological Service (KMS). Model outputs included both baseline and a range of future scenarios from Commonwealth Scientific and Industrial Research Organization (CSIRO) model whose resolution is 1.8°(~ 200 km) and Providing Region Climate for Impact Studies (PRECIS) model whose resolution is 0.44°(~ 50 km). The PRECIS climate model is an atmospheric and land surface model of limited area and high resolution which is locatable over any part of the globe (Wilson et al., 2010). CSIRO Mark 3.6 (CSIRO-Mk3.6) climate system model was developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) in Australia at the CSIRO Australian Numerical Meteorology Research Centre. In contrast to the SRES scenarios, RCPs represent pathways of radiative forcing, not detailed socio-economic narratives or scenarios (Hijioka et al., 2008). Table 1 shows the locations of stations used in the study. The period of 1961-1990 and 2005-2050 was used for baseline and future scenarios respectively. PRECIS Model scenarios included A1B and A2, while CSIRO Mk3.6 model scenarios included RCP 4.5Wm-2 and RCP 6.0Wm-2 PRECIS, a product of the UK Met Office, relies exclusively on the Hadley Centre’s GCMs at present, and is the most widely used downscaled model in Africa. The stations used in the study are presented in Table 1.

The trend of rainfall and temperature was determined using nonparametric Mann Kendall trend test (Mann, 1945) due to its robustness against departures from normality. It tests whether Y (temperature and rainfall) values tend to increase or decrease with T (monotonic change) and used specifically to determine whether the central value or median changes over time. The variability of rainfall and temperature data were also determined using the coefficient of variation. The drought condition over Tana River County was evaluated using the Standardized Precipitation Index (SPI). SPI is a probability index that was developed to give a better representation of abnormal wetness and dryness. It uses

Figure 1. A map of Tana River County of Kenya.

Table 1. List of stations used in the study.

Station	Lat	Lon	Station	Lat	Lon	Station	Lat	Lon	Station	Lat	Lon
Bangali	-0.73	39.0	Malindi	-3	40	Kipini	-1.5	40.0	Kitui	-1.38	37.99
Madogo	-0.47	39.6	Garissa	0.45	39.6	Garsen	-2	40.1	Lamu	-2.2	40.9
Bura	-2.53	40.5	Mwingi	-0.2	38	Wenje	-1	40	Ijara	-1.6	40.5

a gamma or a Pearson Type III distribution and can be created for differing periods of 1 to 36 months. In this study, a 12-month period was adopted. Negative values indicate drought conditions while positive values are for wet conditions. Later, the computed SPI values were utilized for further studies to analyze the beginning and terminating intensity, frequency or return period and the probability of occurrence of drought. The following equation was used to calculate the probability of occurrences and the corresponding risk values (Nazarifar et al., 2014):

$$P_{(N,m,n)} = \frac{n-m+1}{N+n-2m+2} \quad (1)$$

Where N is the length of data, m is the duration of drought and m is the return period. After quantifying the related risk of return periods of various drought events and with respect to the severity, the corresponding probability of occurrence to the amount of risk was calculated.

RESULTS AND DISCUSSION

Temporal variability of rainfall, minimum and maximum temperature

Trend of past and future rainfall, minimum and maximum temperature based on observed and projected model (PRECIS and CSIRO) output were computed and the

Table 2. Trend analysis of rainfall, minimum and maximum temperature based on Mann Kendall test for A1B and A2 SRES scenarios.

Station	Observed parameters		
	Precipitation (PPT)	Maximum Temperature (TX)	Minimum Temperature (TN)
Garissa	0.0004	< 0.0	< 0.0
Lamu	0.3530	< 0.0	< 0.0
Mombasa	0.0110	< 0.0	< 0.0
Mwingi	0.0006	< 0.0	< 0.0

Table 3. Trend analysis of rainfall, minimum and maximum temperature based on Mann Kendall test for A1B and A2 SRES scenarios.

Station	Baseline			SRES Scenarios					
	PPT	TX	TN	P-A1B	P-A2	TX-A1B	TX-A2	TN-A1B	TN-A2
Bangali	0.00	< 0.0	< 0.0	0.53	0.01	< 0.0	< 0.0	< 0.0	< 0.0
Bura	< 0.0	< 0.0	< 0.0	0.59	< 0.0	< 0.0	< 0.0	< 0.0	< 0.0
Garissa	< 0.0	< 0.0	< 0.0	0.84	0.11	< 0.0	< 0.0	< 0.0	< 0.0
Garsen	< 0.0	< 0.0	< 0.0	0.83	< 0.0	< 0.0	< 0.0	< 0.0	< 0.0
Ijara	< 0.0	< 0.0	< 0.0	0.58	< 0.0	< 0.0	< 0.0	< 0.0	< 0.0
Kipini	< 0.0	< 0.0	< 0.0	0.97	< 0.0	< 0.0	< 0.0	< 0.0	< 0.0
Kitui	0.22	< 0.0	< 0.0	0.41	0.08	< 0.0	< 0.0	< 0.0	< 0.0
Lamu	< 0.0	< 0.0	< 0.0	0.56	< 0.0	< 0.0	< 0.0	< 0.0	< 0.0
Madogo	< 0.0	< 0.0	< 0.0	0.77	0.00	< 0.0	< 0.0	< 0.0	< 0.0
Malindi	< 0.0	< 0.0	< 0.0	0.50	< 0.0	< 0.0	< 0.0	< 0.0	< 0.0
Mwingi	0.35	< 0.0	< 0.0	0.57	0.04	< 0.0	< 0.0	< 0.0	< 0.0
Wenje	< 0.0	< 0.0	< 0.0	0.63	< 0.0	< 0.0	< 0.0	< 0.0	< 0.0

Table 4. Trend analysis based on Mann Kendall test for A1B and A2 SRES temperature and rainfall.

Station	Baseline			RCP 4.5 Wm-2			RCP 6.0 Wm-2		
	PPT	TX	TN	PPT	TX	TN	PPT	TX	TN
Bangali	0.00	< 0.0	< 0.0	0.33	< 0.0	< 0.0	0.13	< 0.0	< 0.0
Bura	< 0.0	< 0.0	< 0.0	0.39	< 0.0	< 0.0	0.19	< 0.0	< 0.0
Garissa	< 0.0	< 0.0	< 0.0	0.64	< 0.0	< 0.0	0.44	< 0.0	< 0.0
Garsen	< 0.0	< 0.0	< 0.0	0.63	< 0.0	< 0.0	0.43	< 0.0	< 0.0
Ijara	< 0.0	< 0.0	< 0.0	0.38	< 0.0	< 0.0	0.18	< 0.0	< 0.0
Kipini	< 0.0	< 0.0	< 0.0	0.77	< 0.0	< 0.0	0.57	< 0.0	< 0.0
Kitui	< 0.0	< 0.0	< 0.0	0.21	< 0.0	< 0.0	0.01	< 0.0	< 0.0
Lamu	< 0.0	< 0.0	< 0.0	0.36	< 0.0	< 0.0	0.16	< 0.0	< 0.0
Madogo	< 0.0	< 0.0	< 0.0	0.57	< 0.0	< 0.0	0.37	< 0.0	< 0.0
Malindi	< 0.0	< 0.0	< 0.0	0.30	< 0.0	< 0.0	0.10	< 0.0	< 0.0
Mwingi	< 0.0	< 0.0	< 0.0	0.37	< 0.0	< 0.0	0.17	< 0.0	< 0.0
Wenje	< 0.0	< 0.0	< 0.0	0.43	< 0.0	< 0.0	0.23	< 0.0	< 0.0

results are presented in Tables 2 to 4.

Table 2 shows that computed p values for observed rainfall and temperature over Garissa, Mombasa and Mwingi stations are lower than the significance level alpha (0.05). The null hypothesis, H0 of no change is rejected and the alternative hypothesis, Ha, accepted and

Table 5. Coefficient of variability of observed rainfall, maximum and minimum temperature.

Station	PPT	Tx	Tn
Lamu	3.71	0.04	0.05
Garissa	5.71	0.11	0.12
Mwingi	4.19	0.07	0.08
Mombasa	3.13	0.03	0.02

thus it is concluded that there is a monotonic trend in rainfall, maximum and minimum temperature over time. However, the computed p value over Lamu station was greater than the significance level alpha (0.05) and thus the null hypothesis H0 cannot be rejected. The risk to rejecting the null hypothesis H0 while it is true is 35.27%. In Table 3, computed p values based on PRECIS baseline data over all stations were lower than the significance level alpha (0.05), an indication of significant positive trend except rainfall over Mwingi and Kitui stations. Projected temperature from PRECIS A1B and A2 SRES scenarios showed a monotonic trend. Projected rainfall indicated a monotonic trend for A2 SRES scenario, while the A1B showed no significant trend. In Table 4, it was noted that the computed p values for temperature (maximum and minimum) for historical, RCP 4.5 Wm-2 and RCP 6.0 Wm-2 showed a positive trend. Significant trend in rainfall was noted for all historical and kitui stations (RCP 6.0 Wm-2). Based on the observed, PRECIS model and CSIRO model data, precipitation was noted to have the highest temporal variability in Tana River County.

Spatial variability of rainfall, minimum and maximum temperature

Based on the coefficient of variability, the spatial variability of rainfall, minimum temperature and maximum temperature were analyzed and the results are presented in Tables 5 to 7.

The coefficient of variability values in Table 5 (observed), Table 6 (PRECIS) and Table 7 (CSIRO) indicate that observed precipitation is highly variable in space compared to both maximum and minimum temperature over Tana River County. Notably, observed coefficient of variability values for precipitation in Garissa and Mwingi stations located inland were high compared to Lamu and Mombasa located near the Indian Ocean (Table 5). The coefficient of variability computed for temperature based on Observed data, PRECIS model and CSIRO model output were all less than zero. In Table 6, the coefficient of variability in the A2 scenario was noted to be higher than the A1B scenario. Although the projected precipitation variability was noted to be higher for CSIRO model (Table 7), the RCP 4.5 Wm-2 showed the highest variability compared to RCP 6.0 Wm-2 . Generally, projected precipitation variability was noted in Tables 6 and 7 to be higher in CSIRO model, a GCM used in the study compared to PRECIS model output and attributed to the ability of the PRECIS model, a regional circulation to capture fine details compared to CSIRO model which is a General Circulation Model.

Monitoring drought conditions over Tana River County

Past drought conditions over Tana River County

Time series of computed past SPI are presented in Figures 2 to 4 for the selected stations over Tana River County. In Figure 2a, a decreasing pattern observed from SPI values based on observations indicated an increase in dry conditions. The drought conditions were mainly observed in the years 1975, 1976, 1980, 1981, 1983 and 1985. Studies (Ininda et al., 2007; Okoola et al., 2008; Ngaina, 2012) attributed the observed drought conditions over the region to EL Nino Southern Oscilation (ENSO) event especially the La Nina. Further, recent drought conditions were observed in 2001, 2004 and 2009 (Figure 2b). Similarly, baseline data from PRECIS model (Figure 3) and historical data from CSIRO model (Figure 4) affirmed the observations that drought conditions were actually increasing in frequency.

Projected drought conditions over Tana River County

Time series of computed projected SPI are presented in Figures 5 to 8 for the selected stations over Tana River County.

Based on PRECIS A1B scenario (Figure 5), drought conditions were noted to increase in magnitude and frequency with the years 2011, 2014, 2015, 2018, 2021, 2025, 2036, 2040 and 2046 expected to experience drought conditions. Under the A2 scenario (Figure 6), wet and dry conditions are observed to alternate in approximately equal magnitude and frequency with years such as 2012, 2014, 2018, 2026, 2031, 2035, 2041 and 2043 expected to experience severe drought conditions. Similarly, the RCP 4.5Wm-2 scenario (Figure 7) and RCP 6.0Wm-2 scenario showed that years 2009, 2012, 2016, 2021, 2024, 2029, 2032, 2039 and 2042 are expected to experience most severe drought conditions. However, under the RCP 6.0Wm-2 scenario (Figure 8), the magnitude and severity of the drought conditions was noted to reduce as compared to RCP 4.5Wm-2 scenario.

Risk analysis of drought conditions over Tana River County

Risk analysis for most intense/severe droughts for 30 years return period and corresponding probability of occurrence for various risk values were calculated based on PRECIS Model and Observed Station data and presented in Tables 8 and 9 respectively.

Table 6. Coefficient of variability for PRECIS rainfall, maximum and minimum temperature.

Station	Baseline			A1B Scenario			A2 Scenario		
	PPT	TX	TN	PPT	TX	TN	PPT	TX	TN
Bangali	2.30	0.08	0.07	1.95	0.08	0.07	3.4	0.07	0.07
Bura	3.02	0.05	0.04	1.38	0.06	0.05	3.41	0.06	0.05
Garissa	2.39	0.08	0.07	2.14	0.08	0.06	3.24	0.07	0.07
Garsen	1.94	0.08	0.05	1.72	0.08	0.06	3.40	0.07	0.06
Ijara	1.80	0.09	0.05	1.60	0.08	0.05	3.20	0.07	0.06
Kipini	2.01	0.08	0.06	1.77	0.08	0.06	3.31	0.07	0.06
Kitui	1.96	0.10	0.11	1.92	0.09	0.10	2.63	0.08	0.10
Lamu	2.00	0.04	0.03	1.35	0.07	0.05	3.26	0.06	0.05
Madogo	2.36	0.08	0.07	1.90	0.08	0.06	3.45	0.06	0.07
Malindi	2.66	0.04	0.04	1.48	0.07	0.05	3.54	0.06	0.05
Mwingi	2.09	0.09	0.09	3.01	0.07	0.07	4.08	0.07	0.07
Wenje	2.14	0.08	0.06	1.85	0.08	0.06	3.46	0.06	0.07

Table 7. Coefficient of variability for CSIRO rainfall, maximum and minimum temperature.

Station	Baseline			RCP 4.5 Wm-2			RCP 6.0 Wm-2		
	PPT	TX	TN	PPT	TX	TN	PPT	TX	TN
Bangali	4.52	0.06	0.08	4.63	0.06	0.08	4.47	0.06	0.08
Bura	4.52	0.06	0.08	2.64	0.04	0.05	2.31	0.04	0.05
Garissa	4.86	0.05	0.09	4.80	0.05	0.09	4.65	0.05	0.08
Garsen	3.75	0.06	0.06	4.16	0.06	0.06	3.86	0.06	0.06
Ijara	4.93	0.05	0.06	5.10	0.05	0.06	4.77	0.05	0.05
Kipini	4.52	0.06	0.08	4.63	0.06	0.08	4.47	0.06	0.08
Kitui	3.57	0.07	0.12	3.39	0.07	0.12	3.44	0.07	0.11
Lamu	2.28	0.04	0.05	2.64	0.04	0.05	2.31	0.04	0.05
Madogo	4.52	0.06	0.08	4.63	0.06	0.08	4.47	0.06	0.08
Malindi	3.75	0.06	0.06	4.16	0.06	0.06	3.86	0.06	0.06
Mwingi	3.57	0.07	0.06	4.16	0.07	0.12	3.44	0.07	0.11
Wenje	4.52	0.06	0.08	4.63	0.06	0.08	4.47	0.06	0.08

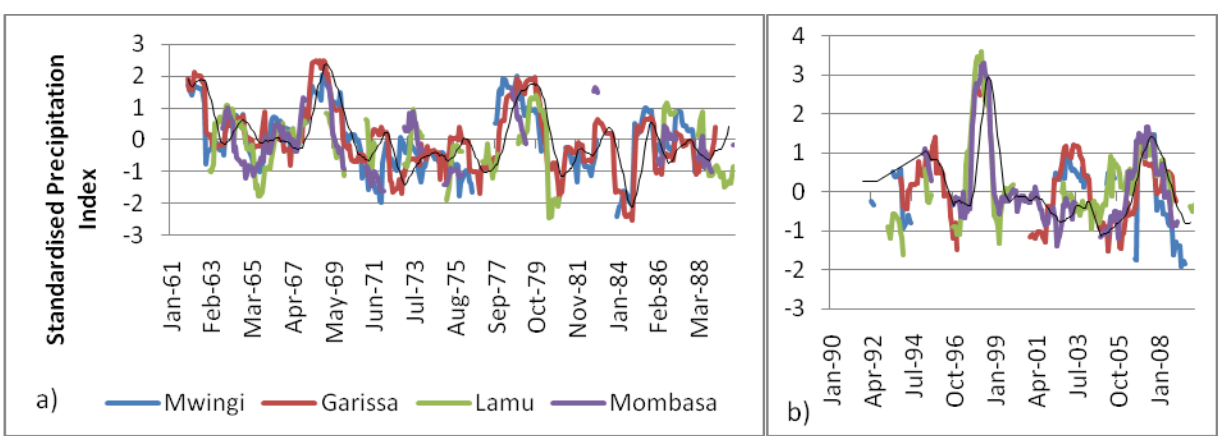

Figure 2. Observed Standardized Precipitation Index for: (a) 1961-1989 and (b) 1990-2008.

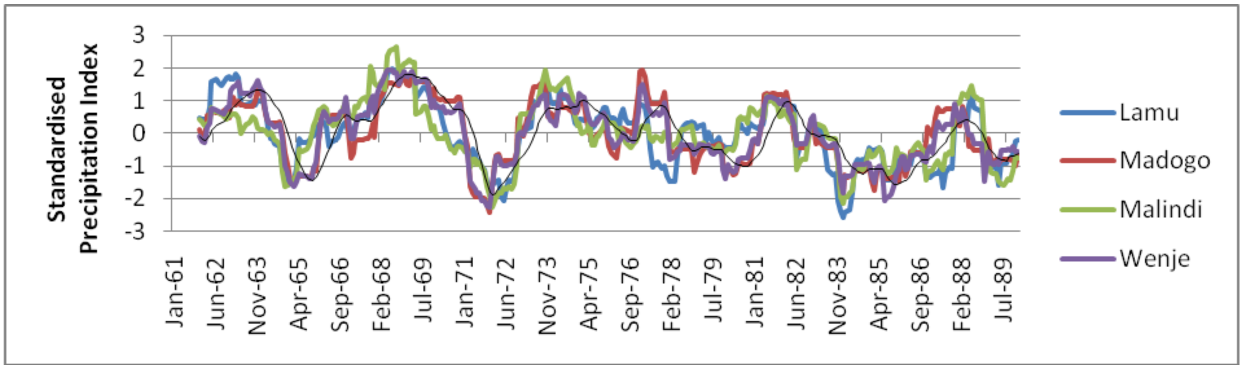

Figure 3. Standardized Precipitation Index based on PRECIS model.

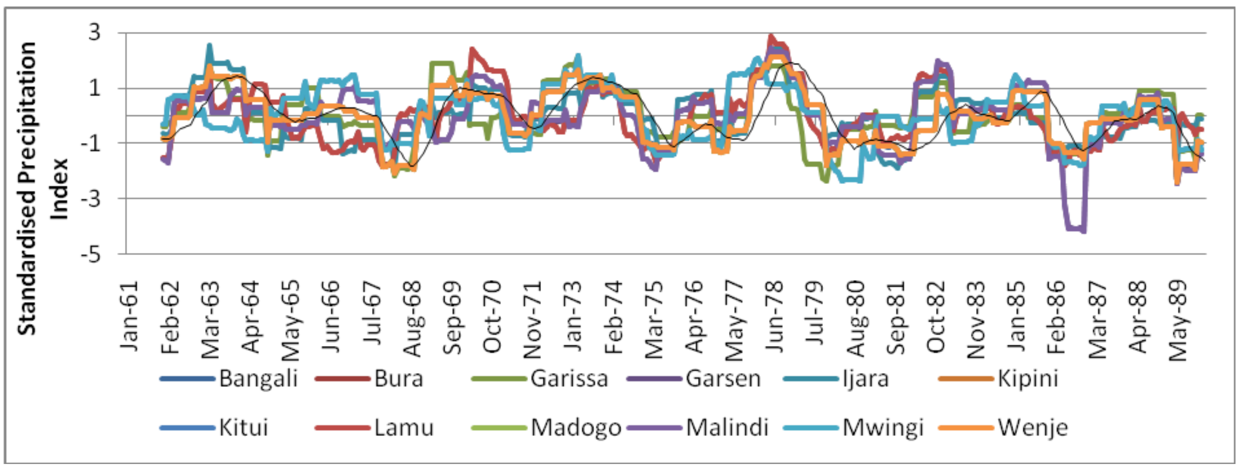

Figure 4. Standardized Precipitation Index based on CSIRO model.

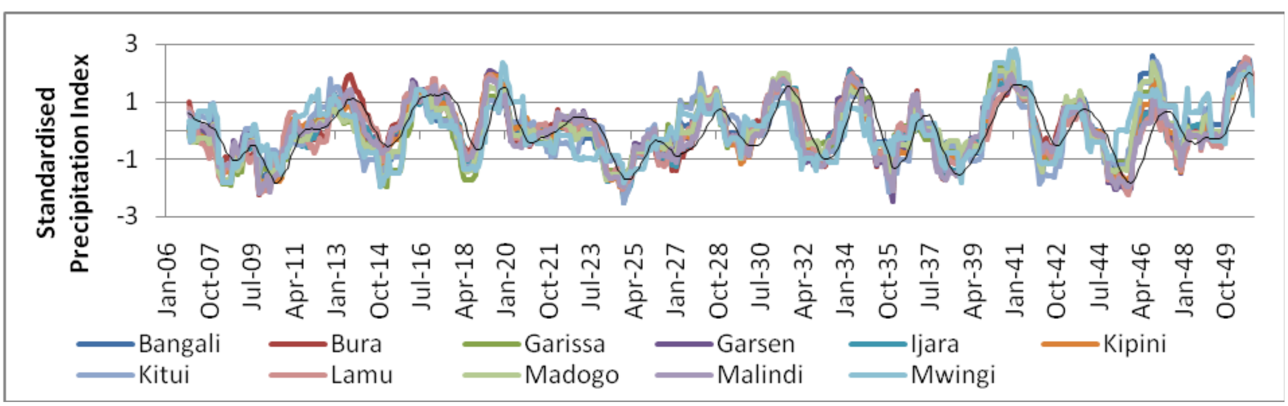

Figure 5. Standardized Precipitation Index based on A1B scenario.

Table 8 indicates that north (Bangali and Madogo) and central region (Bura) of Tana river county were susceptible to intense drought conditions which were projected to shift northwards under all SRES scenarios. Notable, probability of occurrence of drought conditions was noted to be above 50%. This indicated that Tana

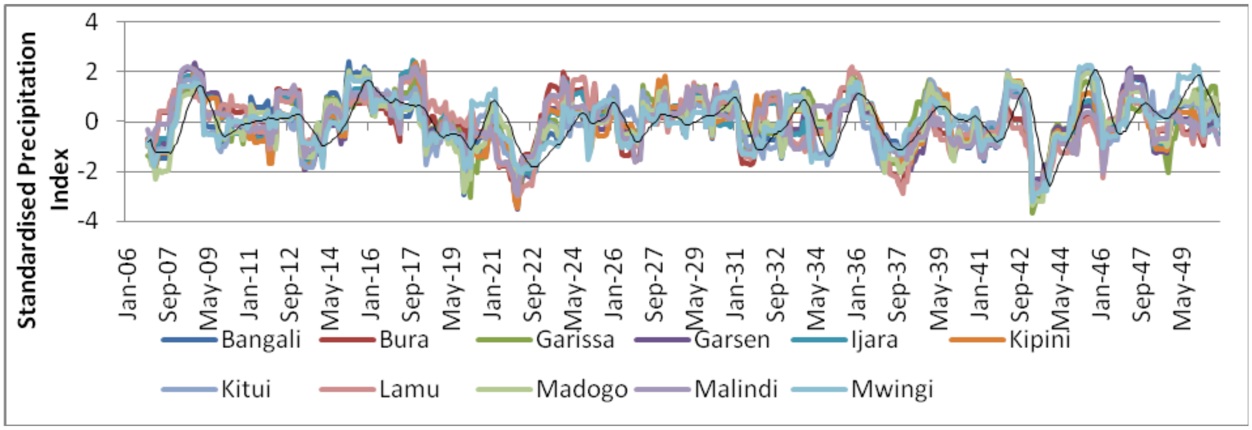

Figure 6. Standardized Precipitation Index based on A2 scenario.

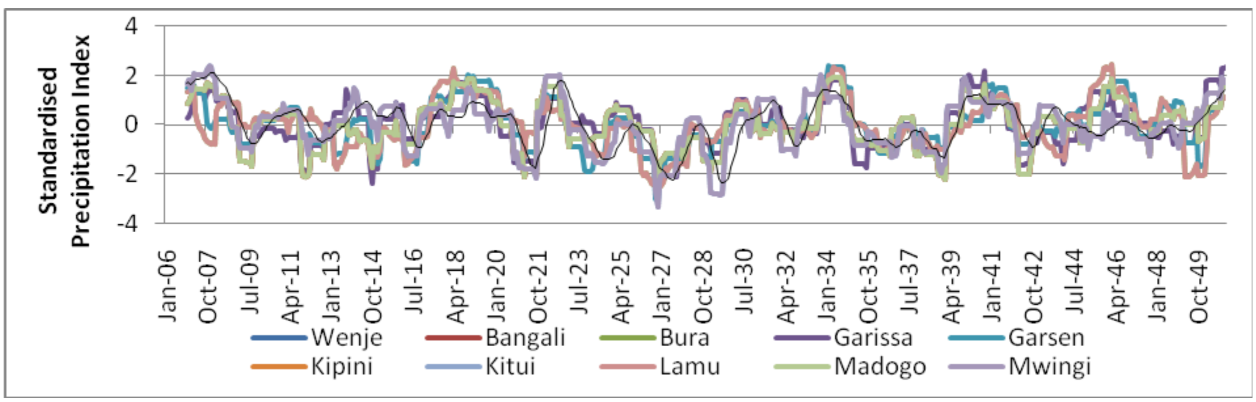

Figure 7. Standardized Precipitation Index based on RCP 4.5 Wm-2 scenarios.

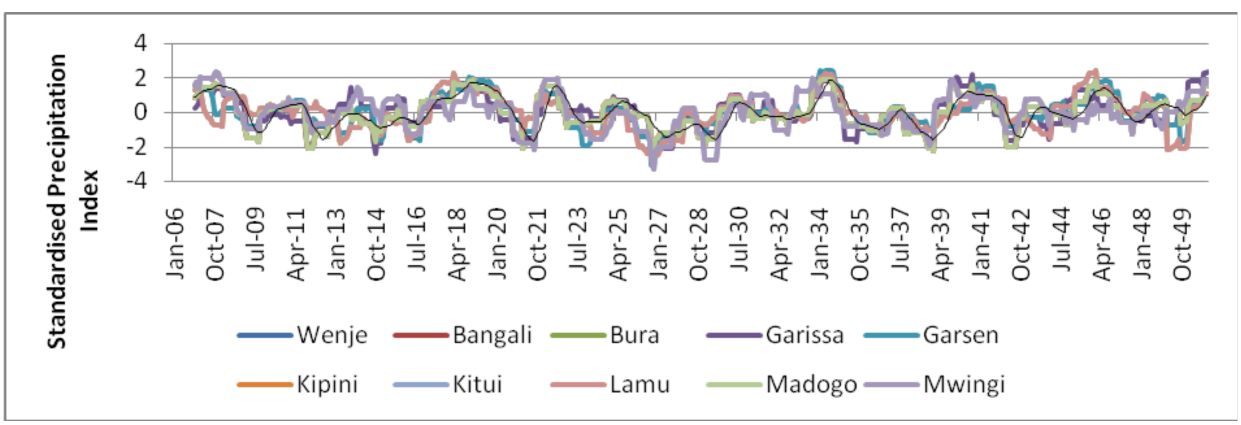

Figure 8. Standardized Precipitation Index based on RCP 6.0 Wm-2 scenarios.

River County remains highly susceptible to drought conditions and hence will directly impact on livestock production which is the main economic activity in the region.

Conclusion

Variation of past rainfall amount which has been reducing over the years in Tana River County with projected

Table 8. Risk values and probability of occurrence for 30 years return period drought for PRECIS model and observed station data based on intensity according to SPI.

Station	Baseline			A1B Scenario			A2 Scenario		
	D	R (%)	PoO	D	R (%)	PoO	D	R (%)	PoO
Bangali	34	76.9	High	37	77.8	High	37	78.9	High
Bura	37	63.2	Probable	40	64	Probable	40	65.2	Probable
Garissa	25	58.5	Average	28	59.2	Average	28	60.5	Probable
Garsen	32	51	Average	35	52.4	Average	35	53	Average
Ijara	29	58.7	Average	32	59.5	Average	32	60.2	Probable
Kipini	27	56.8	Average	30	57.74	Average	30	58.3	Average
Kitui	42	62.3	Probable	45	63.38	Probable	45	63.8	Probable
Lamu	33	53.9	Average	36	55.12	Average	36	55.4	Average
Madogo	36	68.9	Probable	39	70.26	High	39	70.4	High
Malindi	37	65.3	Probable	40	66.8	Probable	40	67.8	Probable
Mwingi	38	60.1	Probable	41	59.6	Average	41	62.6	Probable
Wenje	27	52.4	Average	30	55.18	Average	30	54.9	Average
*Garissa	23	56.9	Average						
*Lamu	30	55.6	Average						
*Mombasa	35	60.0	Probable						
*Mwingi	36	62.5	Probable						

Note: D=Duration, R=Risk, PoO=Probability of occurrence, while * indicates Gauging stations.

climate conditions expected to increase the frequency and magnitude of drought events under all scenarios will exacerbate the aridity already being experienced over the region. The study notes that SPI effectively represents the amount of rainfall over a given time scale, with the advantage that it provides not only information on the amount of rainfall, but that it also gives an indication of what this amount is in relation to the normal, thus leading to the definition of whether a station is experiencing drought or not. The WMO recommends that all national meteorological and hydrological services should use the SPI for monitoring of dry spells. The standardization of the SPI allows the index to determine the rarity of a current drought. Risk analysis based on SPI index indicated that north and central region of Tana River county were susceptible to intense drought conditions which were projected to shift northwards under all SRES scenarios. This is expected to increase conflicts due to limited water resources, pasture and food insecurity in the region and thus limit achievement of Kenya's long term development envisioned in the Vision 2030. Critical interventions would be monitoring climate change and disseminating information to farmers through agricultural extension, to encourage both short- and long-term adaptations. Improved management and conservation of available water resources, water harvesting and recycling of waste water could also generate more water not only for livestock production but also irrigation, which is important in the arid and semi-arid areas. Policies for credit provision and improved household welfare are also a priority for both short- and long-term adaptation measures.

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