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Assessment of Climatic Variability and Development of Localized Climate Prediction Method for Livestock Production in Borana Area, Southern Ethiopia

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Abstract

This study examines seasonal climate prediction method and evaluates its social and economic values in reducing climate-related hazards on livestock productivity over Borana Zone using monthly rainfall and temperature data recorded over the region for the period of 1983-2014. The predictive potential of March-April-May rainfall amounts and patterns in Borana Zone also examined using statistical methods. In view of this, multivariate statistical techniques were applied to analyze and predict seasonal rainfall. Global and regional climatic processes induced distinct impact on long rainy season over Borana Zone. This was also reflected relatively in regional and local climate drivers. The results revealed that lag relationship between ENSO and homogeneous rainfall regimes El Niño has strong predictability skill for long rainy season of Borana Zone. Furthermore, the study showed that long rain (March-April-May) has declined while temperature over all season has risen throughout the past consecutive decade. Overall, the results as generated from this study revealed that moderate to severe droughts were recurrent, particularly during the main rainy season, which were predicted well in advance using scientific climate prediction tools., Localized seasonal climate prediction tool would therefore be promising to enhance societal preparedness for various climate-relate hazards by availing timely and local-specific weather and climate forecasts.

Keywords:* *ENSO; Homogeneous zone; Predictability skill; Rainy season

Introduction

Arid and semi-arid lands (ASAL) cover nearly two-thirds of the African continent [1]. Among African countries, Ethiopia is home to the largest cattle population in East Africa with approximately 29.5 million heads, which represents almost 30% of the total population of cattle in East Africa which constitutes roughly 90 million heads [2-5]. Also documented that Ethiopia

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has the largest livestock population in Africa, which is closely 60% of the land, area in Ethiopia is pastoral, and most of them reside in Borana Zone. Assessment of climatic variability and analysis its effect on livestock population therefore bears enormous advantages for pastoralist and agropastoralist curbed in arid and semi-arid [1]. As [6] documented climate variability is the way climate fluctuates yearly as above or below of a long-term average value. It is one of the pervasive stresses that individuals and communities in rural areas are entitled to coping with. Human-being recognized millennia ago the importance of climate variability to the sustenance of life, whether that variability was expressed in the form of droughts, floods, heat, cold, or wind [7]. The cattle populations, which are mostly sensitive to climate variability, are located in arid regions [8]. Pastoralists and agro-pastoralists depend directly and indirectly on the products of their livestock, so they have developed multiple coping mechanisms to deal with drought and in the past, adapted very well to climate variability [1]. Recently, an increasing variability in climate reduced the pastoralist's confidence on his or her own predictors and increasingly looking for modern science-based weather forecast. However, the challenge is to provide reliable forecast through appropriate methods based on the needs of the farmers. According to [9] recently traditional methods (as in the past 20 years) seemed to be less predictable.

At present, however, the Borana livestock production system is coming under increasing pressure from various stresses such as degrading, shrinking rangelands, and recurrent climatic shocks [10-13]. Increasing frequency and intensity of droughts accentuates the impacts of these stressors which also undermining the traditional coping strategies and deepening the susceptibility of the Borana pastoralists. Cattle which are the livestock species most susceptible to scarcity of water and forage including a shortage of an erratic rainfall can cause serious range of degradation and loss of livestock in quality and quantity. Heat distresses on animal also reduce the rate of animal feed intake and causes poor performance growth [14,15].

Seasonal climate forecasts provide an indication of how variable the rainfall might be compared to past years and is therefore considered as information that could help to prepare for and adapt to climate variability [16]. Similarly, the most important feature of sea surface temperature variability that can cause large-scale weather disruptions is El Niño and its counterpart La Niña, a near basin-wide warming and cooling of the equatorial Pacific Ocean, known as ENSO [16].

In recent years, localized meteorological monitoring systems have been expanded, pastoralists are willing to accept and practice early warning preparedness. Climate prediction is one of the most important means to minimize climate-related hazards such as droughts in order to increase both quantity and quality of livestock production. For example, [17] noted that climate prediction plays great role to control drought and diseases, which are highly sensitive to climate variability.

With an increasing demand for operational drought and disease early warning systems (EWS), recent advances in the availability of climate and environmental data and increased use of geographical information systems (GIS) and remote sensing enables climate based EWS increasingly feasible from a technical point of view.

The present study was firstly designed to assess climatic variability and its effect on livestock population and develop localized climate prediction method in order to monitor and mitigate impacts of climate-related hazards on livestock productivity over Borana Zone Secondly it was developed to regionalize rainfall patterns of Borana Zone into homogeneous rainfall regimes whereby to develop skillful prediction model for each homogeneous rainfall regimes. Lastly, the study was designed to quantify the statistical relations between ENSO, and other oceanic and atmospheric phenomena and MAM rainfall that allow policy makers, planners and community in general to monitor measure and mitigate impacts of climatic extremes. In general, results generated from this study is intended to provide valuable information and scientific knowledge that used to develop local climate forecast and to mitigate climatic shocks such as drought and flood. In addition, it is expected to contribute to enduring early preparedness and efforts of climate resilient for Borana livestock productivity systems as well as to enhance the livelihood of the people.

Description of Study Area

The study was conducted over Borana Zone, which is located in the south most part of the Ethiopia lowlands occupying a total land area of about 95,000 km^2 between 336’N-6038’N and 33043’E -39030’E, sloping gently from 2702 meters in the north to about 496 meters in the extreme south that borders northern Kenya (FIG. 1).

The area is still predominantly in pastures comprised of flat plains forming the main parts of the range. Cattle is by far the most important livestock species held by the Borana pastoralists and accounts for the about 90% of the total livestock holdings in the area [18]. The area is classified as arid and semi-arid with mean average of annual rainfall 238 mm to 896 mm, mean daily air temperatures ranging between 19°C and 26°C [19]. Annual rainfall regime ranges on average from 300 mm in the south to 900 mm in the North per annual [20] and is bimodal pattern of rainfall, with the long rainy season (Ganna) between March and May, and the short rainy season (Hagayya) between September and November followed by two dry seasons. The remains two seasons are known as dry seasons.

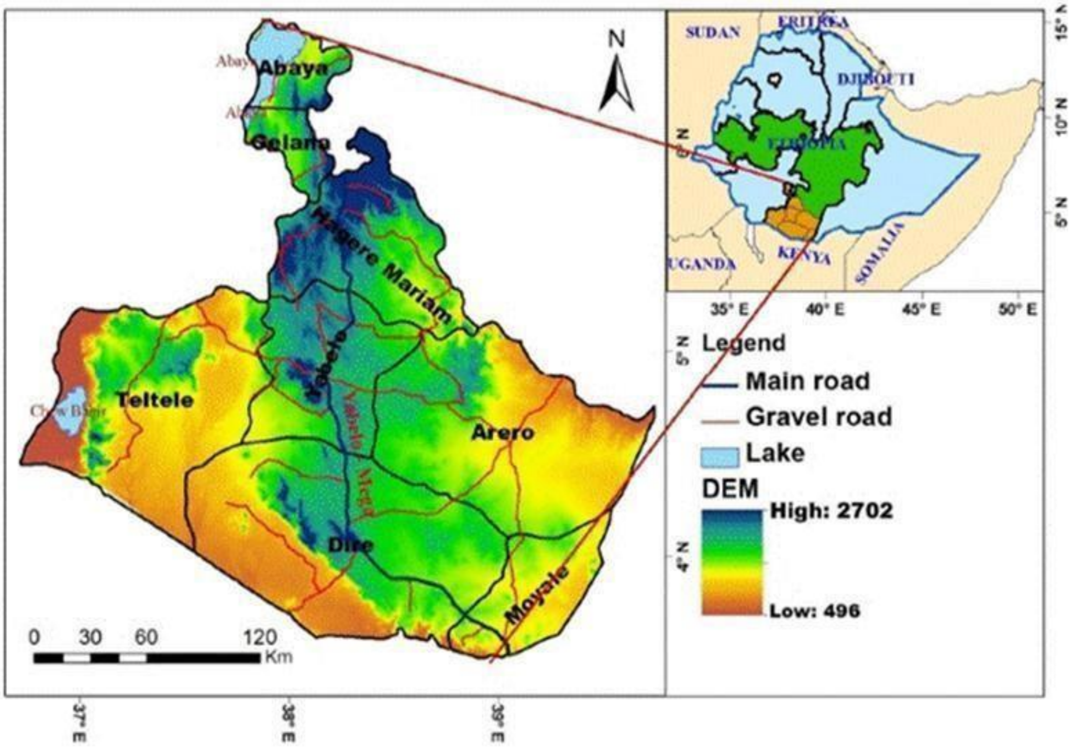


FIG. 1. **Shows map of study area Borana zone over Southern Ethiopia (the scale shows the elevation height over the study area).**

Data and Methodology

Data

The climate data of the study area are obtained both from local and international climate centers. The observed gridded (10 kmx10 km) rainfall data (1983-2014) and surface air temperatures data (1980-2011) at stations level are obtained from 13 National Meteorological Agency of Ethiopia (NMA) stations. Oceanic sea surface temperatures (SST) data obtained from NOAA/NCEP and International Institute for Climate Society (IRI) as well as other international forecast centers (https://www.ncdc.noaa.gov/ and http://www.ncep.noaa.gov/).The livestock populations obtained from Yabelo Agricultural Research Center, Yabelo Pastoralist Development Office and Ethiopian Central statistical Agency (CSA). Missed data were filled according to [21] recommendation, which recommended that missed data is allowable if at least 80% of the years of record are available, with no more than three consecutive missing years.

Methodology

Homogeneous rainfall zones: The rainfall of Borana Zone is categorized into homogeneous rainfall regimes using ground observed gridded meteorological data, rainfall over Borana zone exhibits high spatial variability arid to semi-arid parts so it is useful to divide the zone into homogeneous rainfall zone. In classification of rainfall into homogeneous rainfall regime [22,23] used principal component analysis. In this study also, we use principal component which is built in statistics package for social science (SPSS) software 20, for homogeneous of Borana Zone main rainy season (MAM). The classifications were focus on determination of data of standardized rainfall anomalies which represent the study area by using principal component analysis (PCAs).

The map produced with close analysis of various combinations of the principal components and zones. Out of thirteen such combinations, the first PCs have total variance greater 1 case would have selected as the least noise involved in it. The stations whose monthly rainfall pattern is well correlated and in close proximity to each other tended to be clustered together forming three homogeneous rainfall zones.

Past records of SSTs over 1983-2004 are used to develop the model. Mean of JF SSTs have used to predict MAM rainfall at Borana Zone. Stepwise multiple linear regressions have applied to select predictors that have potential predictive and leave when extra predictors no longer significantly enhance predictive skill. All coefficients are statistically significant at the 95% level, and the overall model “goodness of fit” is significant at 99%. The regression forecasts are shown both within the training period (1983-2004) and for an independent (2005-2014) verification period.

Kaiser-Meyer-Olkin (KMO) and Bartlett’s test: Kaiser-Meyer-Olkin measure of sampling adequacy statistics were used to test factor analysis, which varies between 0 and 1 that a value of close to 0 indicate inappropriate factor analysis and a value close to 1 indicates appropriate factor analysis. Alternative criteria recommend acceptable values greater than 0.5 as acceptable. The Kaiser Criteria classification were mediocre (0.5-0.7), good (0.7-0.8), great (0.8-0.9) and superb (>0.9). Criteria of Bartlett’s significance test were used ($p<0.001$). The Kaiser Criterion communalities after extract are greater than 0.7 and the variable is less than 30.

Seasonal climate prediction method

Statistical climate prediction method: Among seasonal climate prediction methods statistical climate prediction is one of the most familiar [24]. In our current research one month-lead statistical prediction model that relates the monthly SSTs values to the rainfall anomaly prediction was developed using the canonical correlation analysis (CCA) technique, a subroutine that is embedded in climate predictability tool (CPT) of the International Research Institute for climate prediction and society (IRI) [25].

Van den [26] suggested using of standardization of rainfall, so standardized long-year rainfall anomalies is selected from each zone are used in CCA technique that relates patterns in monthly SSTs anomaly of the preseason months used as predictors whereas observed rainfall anomaly data are used as predictands. Under CCA principles, the predictors which have significant correlation with seasonal rainfall anomaly is identified by those oceanic areas having a strong relationship with the respective rainfall zones for a target month, in which a threshold correlation (r) value of $\geq |0.3|$ was taken into account, which amount to a minimum 10% of the variance being explained [27].

Selection of the best predictors: After standardized rainfall anomalies of each zone replaced with all selected potential predictors (NIÑO 3.4, NAO, IOD), the predictors having F-ratio with 95%, P-value <0.05, R^2 and $R>50\%$ significant level were selected to develop the models. The selected predictors would be identified as the candidates which normally be tested or inclusion in the model that should be used to make predictions. The standard approach is to include only those predictors in the final regression equation that contribute to a significant reduce size of the errors [28].

Data analysis

Rainfall and temperature anomaly analysis: The trend of rainfall and temperature were examined using standardized precipitation index (SPI). It provides an area average index of relative rainfall based on the standardization of rainfall totals, and calculated for season and annual. According to [29], the standardized anomalies (Z) of inter-annual variability in rainfall, sea surface temperature (SST) and surface air temperature are calculated as

$$Z = \frac{x - \bar{x}}{SD} \tag{2}$$

Where, x is an annual average, $\bar{x}$ is long-term mean and SD is standard deviation. Annual rainfall variability has been calculated using the coefficient of variation (CV), which expressed as

$$CV = \frac{SD}{\overline{\overline{X}}} \times 100 \tag{3}$$

Where, CV, is coefficient of variation, SD, is standard deviation and $\bar{x}$ is the long-term rainfall mean. The degree of rainfall variability which is CV is classified as less variable (CV<20%), moderate variable (20% to 30%) and high variable (CV> 30%), and CV from moderately variable classified as highly variable and vulnerable to drought as indicated in [30].

Relationship between rainfall and livestock population

Correlation and regression are used to examine relationships between seasonal and annual rainfall and livestock population (Cattle, Camels and Goats). The patterns of inter-annual rainfall variability and fluctuation in livestock population also analyzed to gain a better understanding into rainfall-livestock population relationships in Borana Zone. Similarly, the simply correlation and multi regression analysis is used between rainfall, sea surfaces temperature (SST), and surface air temperature and cattle herds is analyzed with appropriate statistical software such as SPSS version 20, and INSTAT+ 3.37 [31]. A spatial distribution of rainfall and temperatures are analyzed by using Geographical Information System software (Arc GIS) version 10.1.

Results and Discussion

Spatial rainfall distribution of Borana zone

The rainfall pattern of Borana Zone, March- May, the main rainy season, starts from the west side and slightly propagate to north, southwest, and slowly covers central parts of the Zone (FIG. 2). Seasonal distribution of rainfall is more important than total quantity in determining primary productivity [32].

The erratic nature of rainfall of the arid regions in which a large share of annual total rainfall in a few days and lost rapidly through runoff and evaporation, thus seasonal amount and distribution is much more suggestive of rainfall deficits than the annual total [33]. Also indicated total annual rainfall is not a good indicator as compare to seasonal distribution pattern to identify deficits in rainfall. Hence, paying attention to the seasonal distribution of rainfall is virtually important in relating deficits to their negative effects.

As shown in FIG. 2a during the first month of the season, March, good rainfall distributions were observed in West and Southwest parts of the Zone. In contrast, East and Southeast portion of the Zone received less rainfall amount. During April and May, more or less similar patterns of rainfall were observed through the Zone (FIG. 2b and 2c).

In FIG. 2d, good rainfall patterns during MAM season were observed over the northern parts of the Zone while the amount was not good in distribution over the southern parts of the Zone. Maximum magnitude of MAM rainfall was recorded over the northern parts of the Zone which is accounted for mild highland while minimum rainfall was observed over southern parts of the Zone, which perhaps dominates pastoral communities.

Generally, the northern parts of the Borana Zone, which is mild highland experience the better rainfall pattern whereas southern parts of Zone possess similar and but limited rainfall distribution.

Temporal variability of rainfall over Borana zone

Estimation of changes in the seasonal rainfall during the last three decades was weakening due to decreasing pattern in rainfall amount during in April and May. In addition, [34] confirmed that the seasonal rainfall during MAM is erratic and its pattern highly variably in amount. FIG. 3 revealed that rainfall totals during the main rainy season has decreased in the study area. Compared with the long-term average total; it means that the annual rainfall was decreasing at a rate of 0.17 per ten years. It is also clear from the results of the linear trend analysis that the decline in the annual rainfall yield is predominantly because of the substantial decline April and May rainfall, due to this the MAM season reduced over the time. Similar result has been observed is the main cause of the livestock death. As computed to the second season, pastoralist and agro-pastoralist depends highly on the main season rainfall. Hence, decrease the amount of rainfall during season has resulted in tremendous death of livestock population.

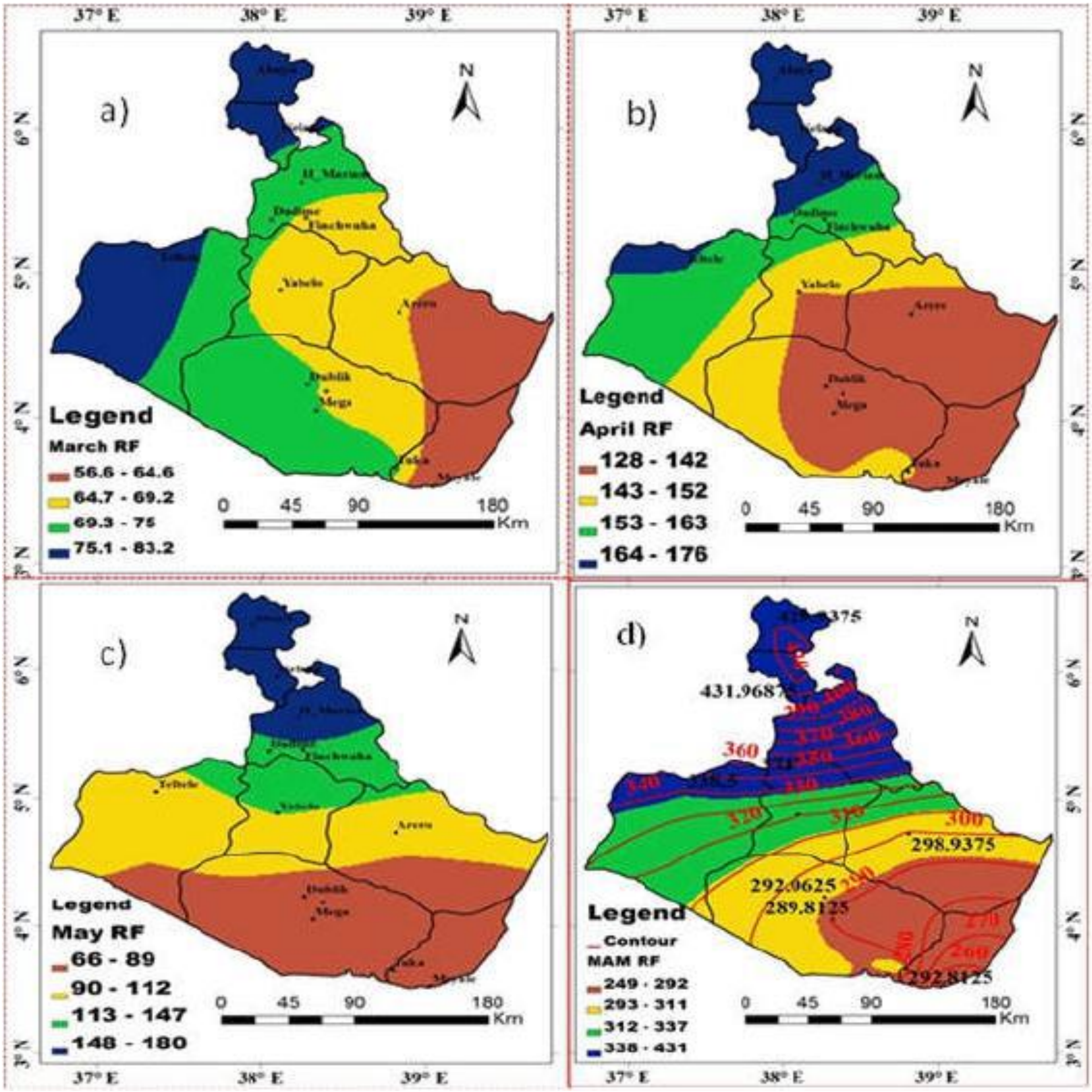


FIG. 2. **Mean rainfall distribution over Borana Zone a. March, b. April, c. May, and d. MAM Zone III weighted standardized MAM seasonal rainfall anomaly from (1983-2014).**

As shown from FIG. 4a, from 1983-2014, the Zone received below and above normal rainfall during MAM season. The red colour indicated the year that of rainfall declined moderate to extreme dry, whereas the green is show the year that rainfall is moderate to extreme wet.

Obviously as the graph shown, the Zone was for 10 years out of thirty-two years and moderate to extreme 4 years out of thirty-two years during MAM season. The Borana Zone arid and semi-arid was consequently for 17 years (from 1988-2004) were near normal to moderate dry (FIG. 4a). Among these seventeen years, four drought years had occurred (1991, 1992, 1999 and 2000) and serious affected massive of cattle mortality. In case of annual rainfall, as trend analysis could have seen from the FIG. 4b, the Zone received 7 years moderate to extreme wet and 8 years moderate to extreme dry out of thirty-two years. Note that rainfall standardized anomalies in seasonal or annual less than negative one (<-1) indicates severe and extreme drought.

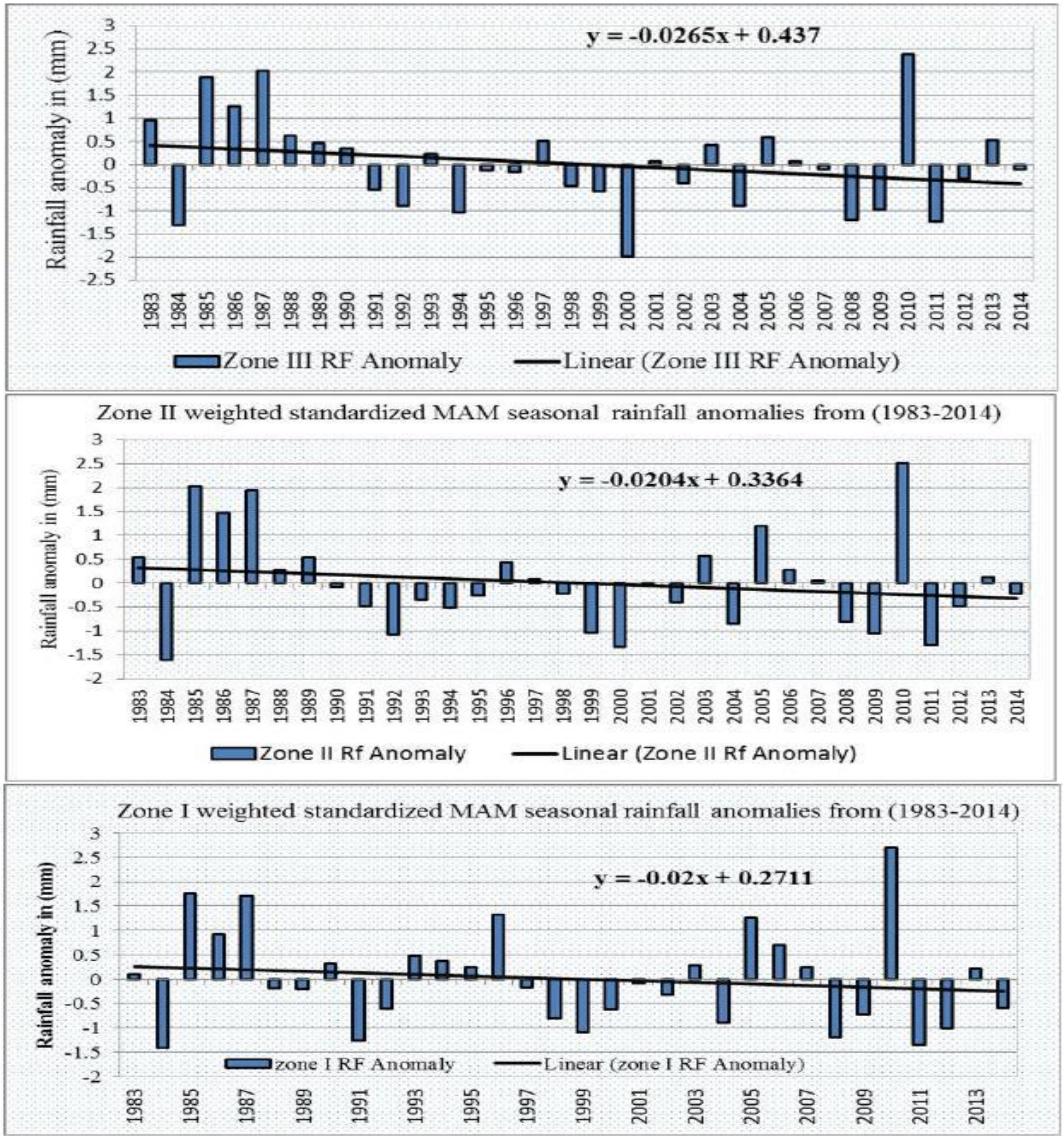


FIG. 3. **Time series of rainfall anomalies and trend over Borana Zone during MAM for Zone I, Zone II and Zone III.**

Annual rainfall pattern of Borana zone

Borana Zone experiences a bimodal seasonal pattern as it lies astride the equator: the long rainy season starts from March and runs through to May, with the peak centered on April; the short rainy season run from September to November (coinciding with Zone) with peak rainfall October (FIG. 5 and FIG. 6).

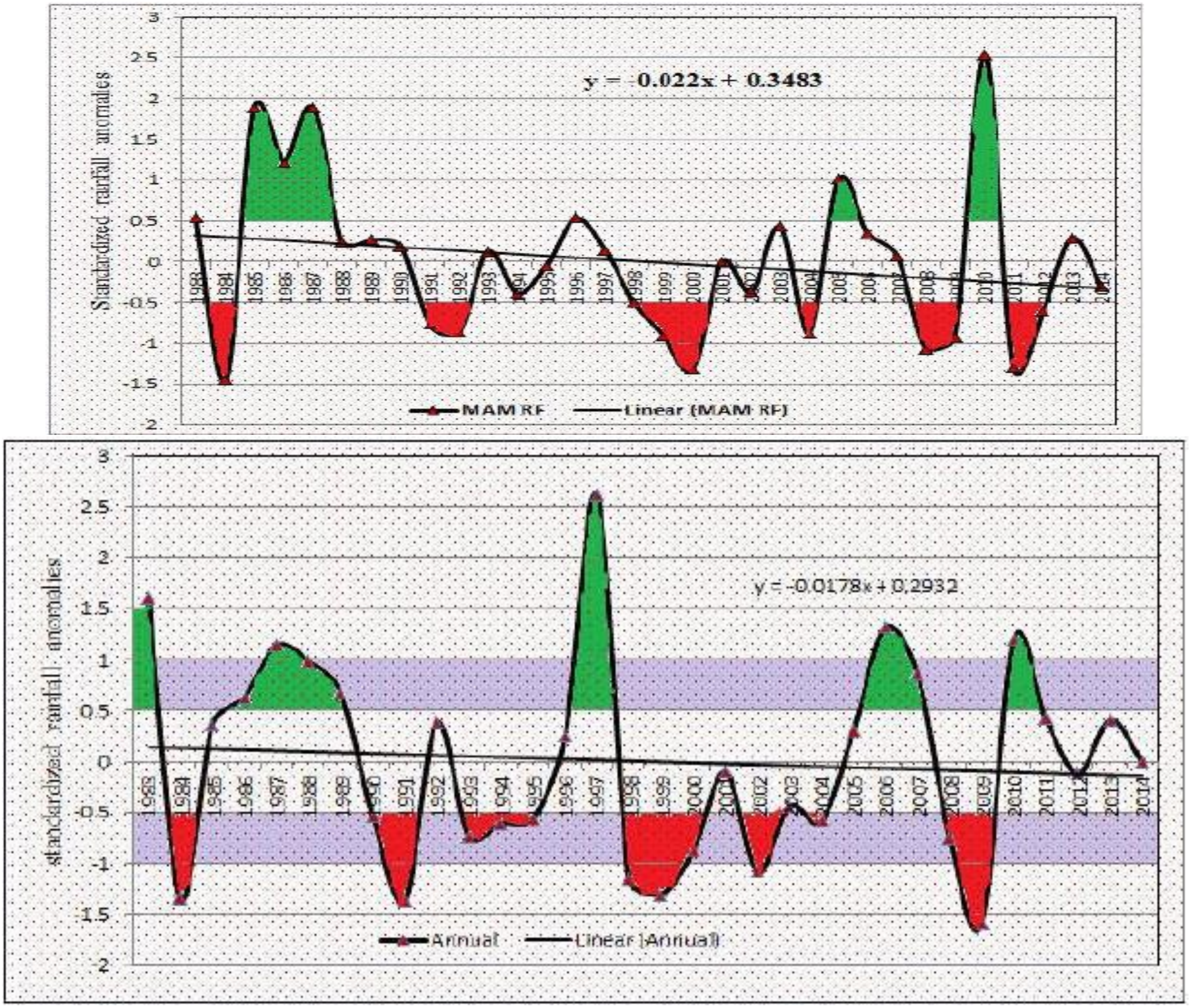


FIG. 4. **Time series of a) MAM and b) annual standardized rainfall anomalies and trend over Borana Zone.**

The source of ITCZ is the development of thermal low over South Sudan generation and propagation of disturbances over the Mediterranean Sea, sometimes coupled with easterly waves and development of high pressure over Arabian Sea. These interactions between mid-latitude depressions and tropical systems accompanied by toughs and the subtropical jet and occasional development of the Red Sea Convergence Zone (RSCZ) [34,35]. For the reason that the Sun is over the equator on 21st March, the tropic of Cancer on 22nd June, the equator again on 22nd December. The interdependence between the Sun and Earth as the Sun's heat causes a low-pressure zone that encircles the earth roughly parallel to the equator, and that moves north and south following the sun, usually with a lag of 4 weeks to 6 weeks [36]. The ITCZ is the result of the convergence of the northern and southern hemisphere trade winds and is characterized by relatively low-pressure zone. Over these ITCZ areas, the weather is quite disturbed, consisting of widespread cloudiness, occasional thunderstorms, and precipitation and moderate to strong winds [37]. Therefore, seasonal climate characteristic of tropic region is depending on the movement of ITCZ, which enhance the movement of air masses.

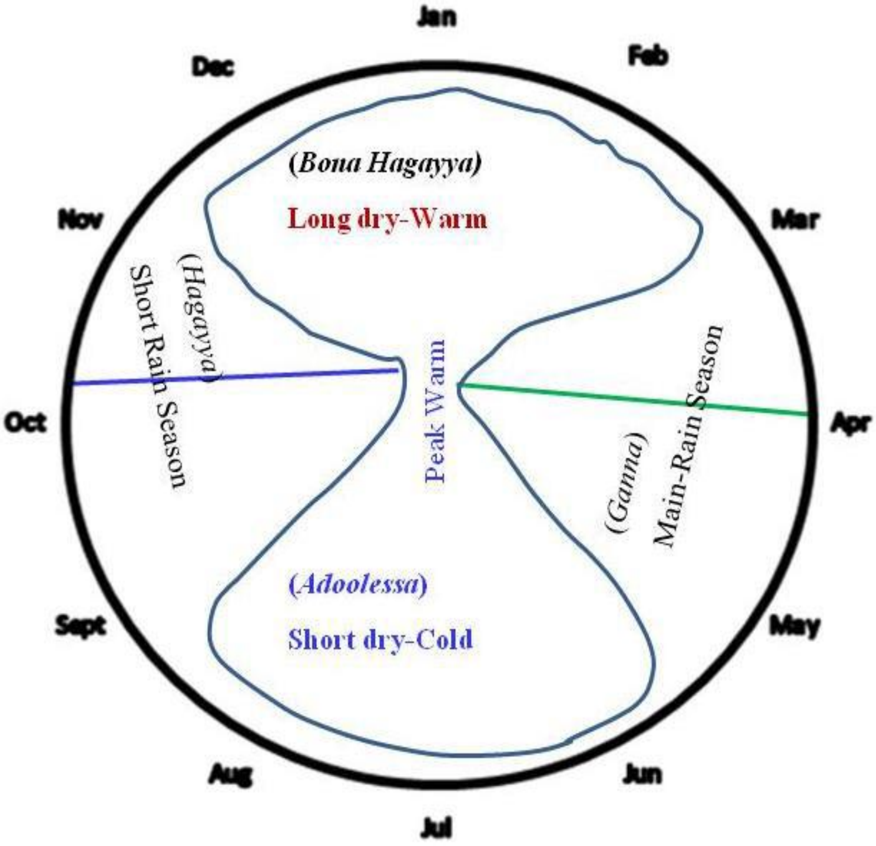


FIG. 5. **Borana Zone annual rainfall cycle.**

The annual rainfall associated to topography and global SST phase, over the highest elevation regimes receive up to 1107 mm per year whilst the low plateau receives only 534 mm. The entire Zone receives less than 432 mm of rainfall preseason, particularly areas around the southern parts of the zone. The FIG. 4b shows as well that annual rainfall is highly variable, especially in the arid and semi-arid regions, and unreliable for rainfall fed agriculture and livestock.

The entire of the districts experienced mean annual rainfall of 738 mm in the period of observation, with a standard deviation coefficient of variation 184 mm and 24.7%, respectably. According to [30], the variation could be taken as moderate. Therefore, the annual rainfall variability was taking as moderate variability. Generally, below average rainfall years were occurred 17 out of the 32 years (FIG. 4a). During the major drought years of 1984, 1991-1992, 2000, 2004 and 2011 the mean MAM seasonal rainfall declined by 37.8%, 22%, 23%, 34%, 24% and 34%, respectively.

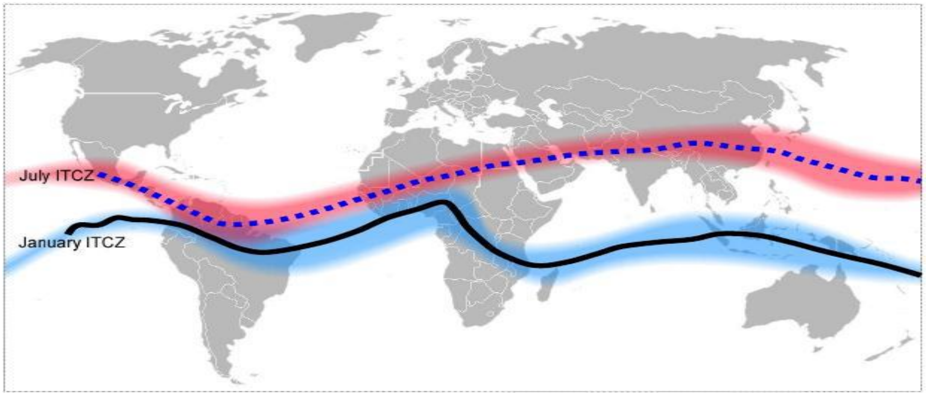


FIG. 6. **Position of inter tropical convergence zone (ITCZ) during January and July months.**

The MAM season total rainfall of Borana zone also varies temporal and spatial, extended from 248 mm to 432 mm, with standard deviation and coefficient of variation 58.8 mm and 17.5%, respectively. This season is the main rainy season of the Zone, which the Borana communities accomplished many activities (TABLE 1).

TABLE 1. **Descriptive statistics of annual and seasonal rainfall at Borana zone.**

Descriptive statistics	**Annual Rainfall (mm)**		**Total Seasonal Rainfall (mm)**		
	Rainfall	**MAM**	**JJA**	**SON**	**DJF**
Minimum	534.4	248.9	47.9	162.8	52
Maximum	1107.2	432	270.5	313.4	95
Mean	738.6	336.3	106.7	221.9	73.6
Range	572.8	183.1	222.6	150.6	43.1
SD	184.1	58.8	69.3	52	12.6
CV	24.9	17.5	65	23.4	17.1
MAM=March, April, May, JJA=Jun, July, August, SON=September, October, November, DJF=December, January, February					

Effects of rainfall variability on cattle mortality

Seasonal patterns in the standardized anomalies of rainfall revealed that the droughts would have revealed by sequential failures in the long and short rain (FIG. 7). Similarly, as [38] documented the droughts revealed Borana Zone is that due to the sequential failure of long rain. In addition, a time series indicates clearly that drought that occurred during 1984, 1992, 2000, 2004, 2009 and 2011 directly associated with the failure of long rainy season (FIG. 7). However, drought events that occurred in 1991, 1999 and were associated with shortening and poor performance of long and short rainy seasons. In recent years, droughts have become severe and recurrent, which occur once in every four to six years from 1983-2014, for instance, among droughts years occurring in Borana Zone, 70% of the events occurred due to declining of long rainy season whereas 30% associated to decline of both rainy seasons. Among drought events that occurred in Borana Zone 1983/84 and 2010/11 were found to be worst incidences that widely affect the Zone.

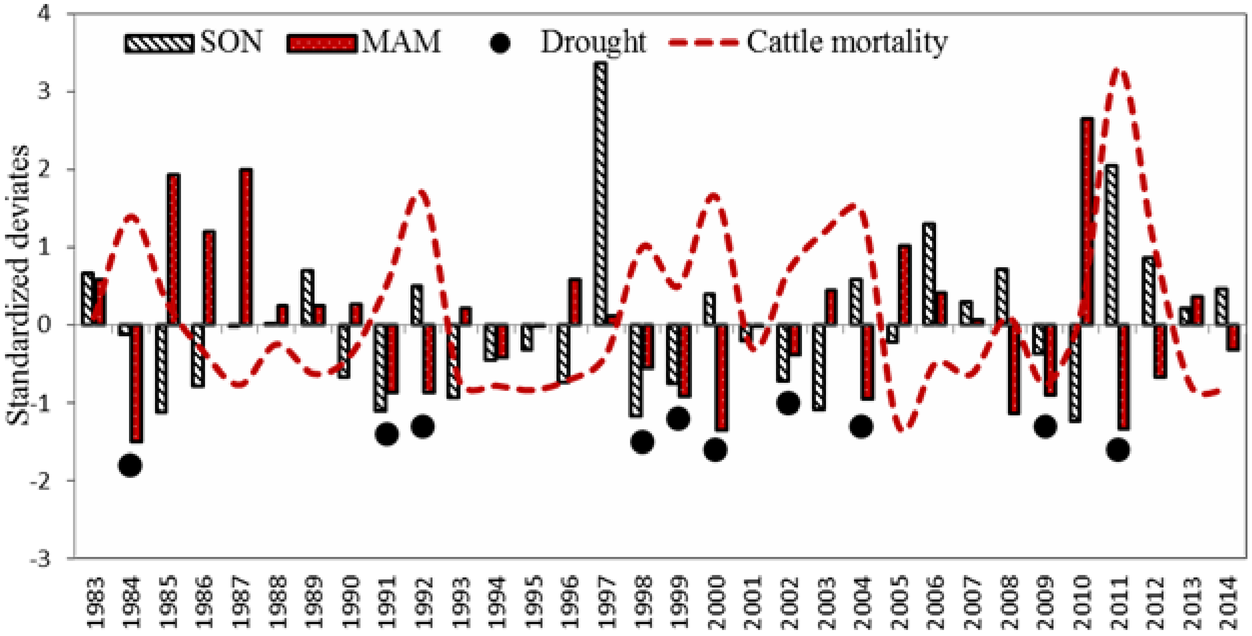


FIG. 7. **Standardized seasonal rainfall anomalies and cattle mortality in Borana zone.**

Standardized rainfall anomalies and percentiles as a measure of drought

In Borana Zone, droughts occur due either failure of the long rain or below average of both short and the long rain. As indicated in FIG. 7, among thirty-two years (1983-2014) the long rain and short rain were below average for 10 and 9 years, respectively. However, failure of the short rain alone may not result in drought if the long rain resumes timely. Drought indicators based purely on precipitation give a good overall view of the situation. According to [38] compared different drought indices for East Africa, concluding that a modified SPI was the best indicator for monitoring East Africa droughts. The risk of heavy livestock losses suffered during recurrent severe droughts associated with rainfall variability presents one of the most serious threats to pastoral livestock keepers.

Drought begins when the standardized rainfall a normally first falls below zero and ends with the first positive value [29]. In addition, drought measured that precipitation below 30th to 20th percentile may indicate mild drought (dry year), 20 to 10th percentile: moderate drought and less than 10th Percentiles severe drought [39].

As FIG. 8 indicated the droughts of 1984, 2000 and 2011 categorized as severe drought their percentiles (3, 6 and 9), respectively. Moreover, drought of 1999, 2004 and 2008 were categorized as moderate drought, their percentiles (19, 16 and 13), respectively. The mild droughts (dry years) were occurred in 1991, 1992 and 2009 years with their percentiles of (28, 25 and 22), respectively.

Generally, from 1983 to 2014 three class of droughts were occurred, which is known as mild (dry year), moderate and severe droughts. Similar to rainfall percentiles also rainfall anomalies clearly, strongly associated with drought events. For instances, the standardized rainfall anomalies values during severe drought years in 1984, 2000 and 2011 was (-1.5, -1.4 and -1.34), respectively.

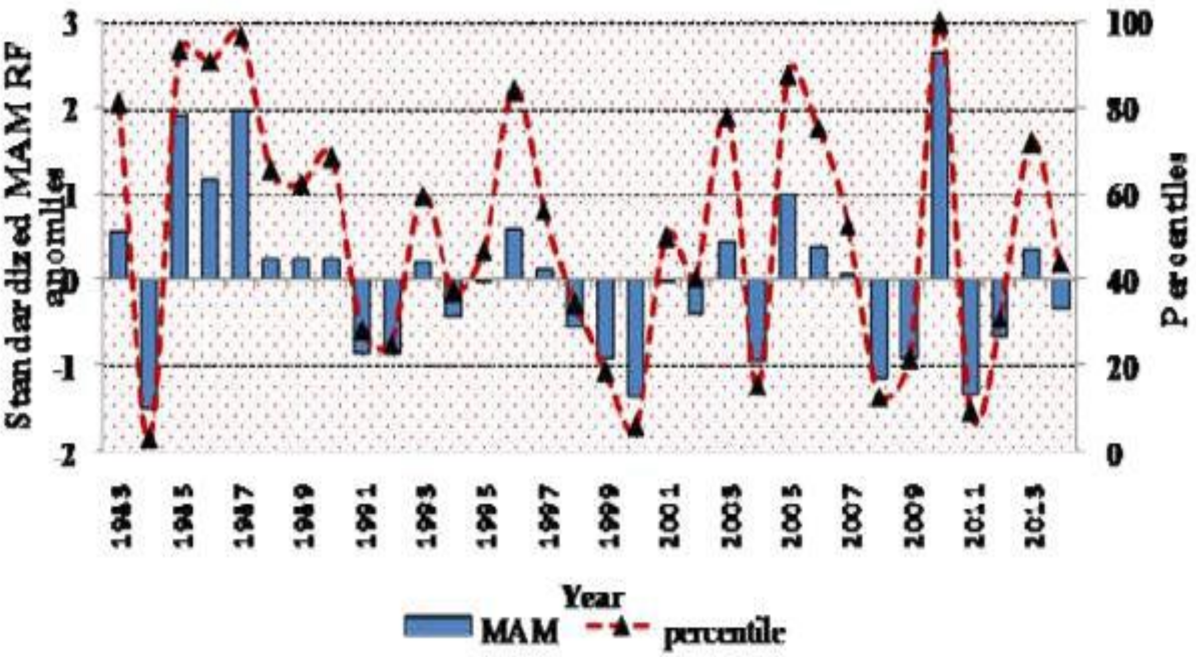


FIG. 8. **Standardized seasonal rainfall anomalies and percentile, were plotted x and y axes, respectively.**

A correlation analysis was used to measure impacts of population dynamics. The analyses revealed that cattle with long rainy (MAM) season ($r=0.629$, $p<0.05$) and goat ($r=0.762$, $p<0.01$) were positively correlated with temperature. Whereas camel was having positive relationship with temperature ($r=0.623$, $p<0.05$) (TABLE 2). The long and short rain had positively correlated with the seasonal changes in cattle numbers, but the correlation is significant with long rain (TABLE 3) and [38]. The annual mean temperature had a negative but insignificant correlation with cattle numbers. The goat and camel numbers were positively correlated with the mean annual temperature; which is significant (TABLE 3) and [38]. Inversely, both goat and camel were negatively correlated with long rain, which is insignificant. In Borana Zone, performance of cattle mainly depends on the long-rainy season (TABLE 4).

TABLE 2. **Time series of multivariate cross correlation matrix.**

Variables	Cattle	Goat	Camel	MAM	SON	Temp
Cattle	1	-0.133	-0.282	0.629*	0.002	-0.417
Goat		1	0.312	-0.282	0.187	0.762**
Camel			1	-0.455	-0.035	0.623*
MAM^{a}				1	-0.218	-0.479

SON[b]					1	-0.071
Temp[c]						1
**. Correlation is significant at the 0.01 level (1 tailed), *. Correlation is significant at the 0.05 Level (1-tailed), [a] MAM: long rain (March-April-May) season, [b] SON: Short rains (September- October-November) season and [c] Temp: Mean Temperature						

TABLE 3. **Relationship between climate variability and ruminant livestock population dynamics in Borana pastoralist area.**

Coefficients Species	**Coefficients B**	**Unstandardized t**		**Standardized Correlation B**	**Value Sig. F**		**Partial**
		Std. Error					
Cattle	(Constant)	824352.76	143192.5		5.757	0	
	Rainfall	948.6	391	0.629	2.43	0.038	0.629
Camel	(Constant)	-407468.4	196665.6		-2.072	0.068	
	Temperature	21090.66	8834.56	0.623	2.387	0.041	0.623
Goats	(Constant)	-2937971.7	1051707.6	0.762	-2.79	0.021	
	Temperature	166775.3	47244.5	0.762	3.53	0.006	0.762

TABLE 4. **Correlations among dependent variables (cattle, goat and camels) and the Predictors (Rainfall and temperature).**

Variations of Statistics								
Model	**R**	**R^2**	**Adjusted R^2**	**Std. Error of the Estimate**	**F Change**	**d1**	**d2**	**Sig. F**
Cattle	0.629[a]	0.395	0.328	117669.2	5.88	1	9	0.038
Goats	0.762[a]	0.58	0.534	104741.1	12.46	1	9	0.006
Camel	0.623[a]	0.39	0.32	19586.2	5.7	1	9	0.041
[a]. Correlation of predictors: rainfall and temperature and dependent variable: Cattle, Camel and Goats whereas correlation is significant at (P is at 0.01 and 0.05)								

Many scholars documented that the study area is commonly known by the persistence of bimodal type of rainfall [34]. Likewise illustrated in FIG. 9 confirmed the study area is clear fall underneath of the bimodal rainfall system.

Clearly understanding of the variability of key MAM characteristics are crucial for Borana pastoralist and agro-pastoralist to manage livestock, to have agricultural planning in general, and especially mitigate the adverse effects of recurring drought and there by fully capitalize when more rain that are abundant occur. Projected for pastoralist and agro-pastoralist communities of Borana region first week of March is to be the potential of planting date.

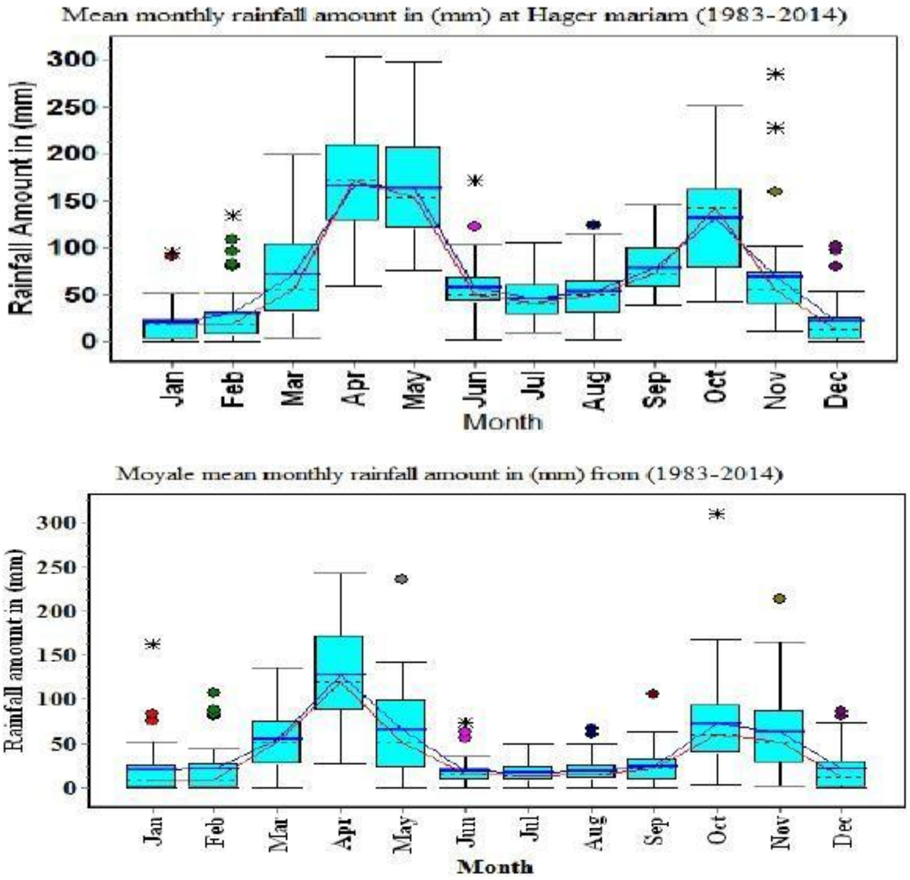
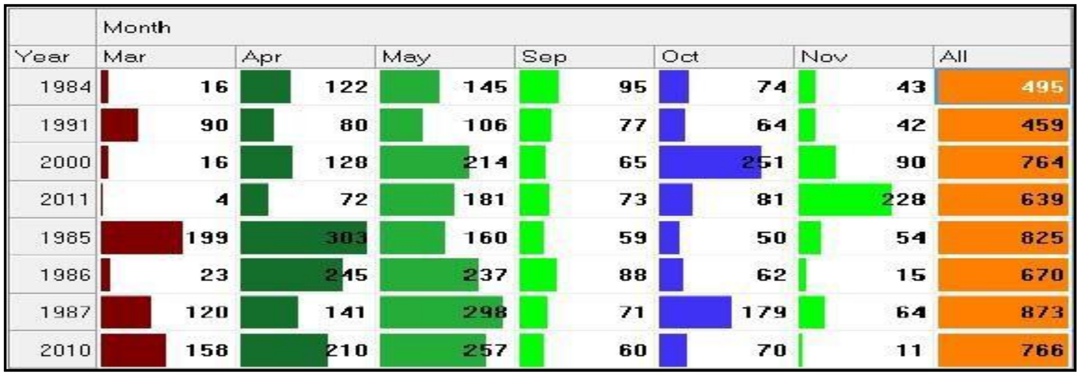


FIG. 9. **Mean monthly rainfall of a) Hagere Mariam and b) Moyale, where solid blue line represents is mean and solid red line represents Median.**

As depicted in FIG. 10, among these eight years special years, like 1984, 1991, 2000, and 2011 were severe droughts years that massive of cattle mortality in Borana zone whereas the years like 1986, 1987, and 2010 wettest years especially during long rainy season. Mostly the droughts observed during the mentioned years have caused cattle death (FIG. 7) due to decline of long rainy season. During these years, the decline of rainfall became less failure of the March rainfall FIG. 10).



	Month						
Year	Mar	Apr	May	Sep	Oct	Nov	All
1984	16	122	145	95	74	43	495
1991	90	80	106	77	64	42	459
2000	16	128	214	65	251	90	764
2011	4	72	181	73	81	228	639
1985	199	303	160	59	50	54	825
1986	23	245	237	88	62	15	670
1987	120	141	298	71	179	64	873
2010	158	210	257	60	70	11	766

FIG. 10**. Monthly rainfall during eight special years (Four drier: 1984, 1991, 2000, 2011and four wettest years: 1985, 1986, 1987, 2010).**

Spatial temperature variability over Borana zone

As depicted in FIG. 11 in Borana arid and semi-arid regions, temperature pattern is varying from district to district. For instance, the lowest minimum temperature distribution was observed over Yabello and Dire districts. However, the minimum temperature distributed over edge of the northern and southern parts of the Zone.

In Borana zone, the lowest mean minimum temperature commonly observed during the June- July-August whereas the highest maximum temperature observed during the long dry (December-January-February) season. As observed from FIG. 11a, the lowest minimum temperature was recorded at dire district while the highest minimum temperature was recorded at Moyale and Abaya. Among the four seasons, JJA season is very cold and dry potentially varying in minimum temperature. The highest maximum temperature has been identified during December-January-February among the four seasons, which adversely affect the livestock production. Rising in temperatures, coupled with declined precipitation reduce crude protein and digestible organic matter contents of the plants, thereby posing nutritional stresses to grazing animals [40].

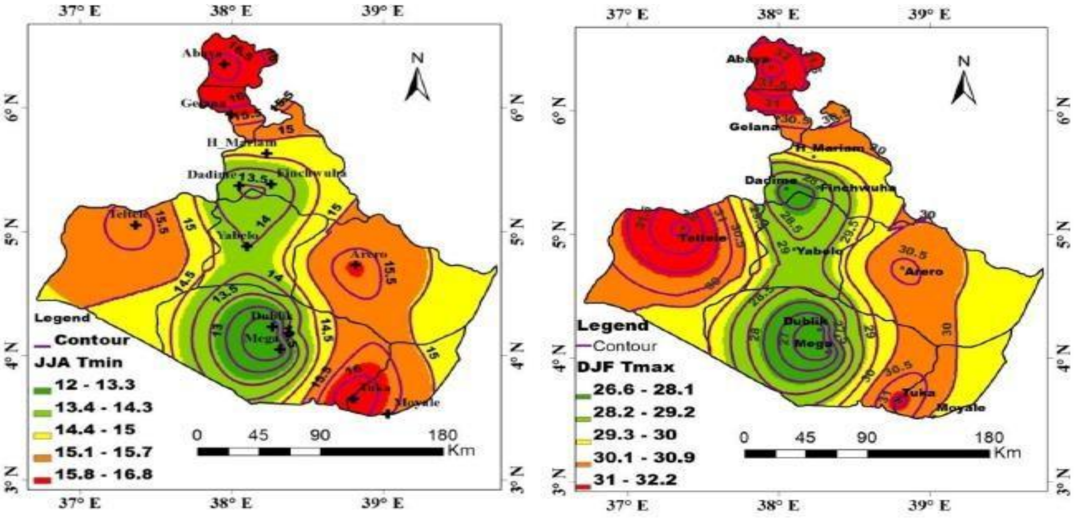


FIG. 11. **Graph showing mean minimum and maximum temperature distribution over Borana Zone for a) JJA T_{min} and b) DJF T_{max}.**

Descriptive temperature analysis

Temperature of Borana zone is rising from time to time. The year to year variation of annual minimum temperatures expressed in terms of temperature-standardized average has increased significantly (FIG. 12). As it could have seen from the FIG. 12, the zone has experienced both warm and cool years over the last 31 years. However, the recent years are the warmest as compared to earlier years. As it shown in FIG. 12, the trend analysis clearly reveals that there has been a warming trend in the annual minimum temperature over the past three decades and it has been increasing by about 0.7°C in every ten years. During the transitional period, short, cold and dry season (JJA) obviously revealed that minimum temperature has substantially increased (FIG. 13). During the JJA season the ITCZ, which associated with low pressure, migrates to the northern parts of Ethiopia. Therefore, during this period Borana zone became cold, cloudy and dry. In addition, as it seen from the box plot, the seasonal minimum temperature is more fluctuated during JJA, which is the main cause for disease outbreak such as foot and mouth. The JJA seasonal minimum temperature has been increasing by about 0.56°C per ten years when it compared to annual minimum temperature. In generally, the observed monthly, seasonal and annual temperature at Borana zone show increasing from time to time, which directly and indirectly affects the livestock production. Many studies [41,42] confirmed that an increase in temperature directly posed thermal stresses on animals; impair feed intake, metabolic activities and defense mechanisms, thereby hindering their production and reproductive performances (TABLES 5 and 6).

TABLE 5. **Descriptive Statistics for monthly and seasonal minimum temperature (°C) at Borana Zone.**

Descriptive statistics	**Jun**	**Jul**	**Aug**	**JJA**
Maximum	17.10	16.70	16.87	16.78
Minimum	12.45	11.78	11.85	12.02
Mean	14.95	14.35	14.54	14.61
Std. Deviation	1.55	1.60	1.61	1.58
CV	10.37	11.15	11.07	10.81

CV= Coefficient Variation, JJA= June-July-August

TABLE 6. **Descriptive Statistics for monthly and seasonal maximum temperature (°C) at Borana Zone.**

Descriptive statistics	**Jan**	**Feb**	**Dec**	**DJF**
Maximum	32.39	33.03	31.69	32.26
Minimum	27.04	27.22	25.61	26.63
Mean	29.68	30.21	28.44	29.44
Std. Deviation	1.87	1.96	1.98	1.93
CV	6.30	6.49	6.96	6.56

CV=Coefficient Variation, DJF= December-January-February

Borana zone, the highest maximum temperature always documented during the DJF season (FIG. 14-16). In addition, the trend line well indicated year to year seasonal maximum temperature with tendency of an increasing trend. The long dry season maximum temperature extends from 29.44°C to 32.26°C with standard deviation and coefficient variation of 1.93% and 6.56%, respectively. The variability of maximum temperature of DJF season was less compared to the variability of JJA minimum temperature. Rising temperatures exacerbate the influence of moisture stress on plant growth and thermal stress on animals by decrease the crude protein and digestible organic matter contents of plants [40].

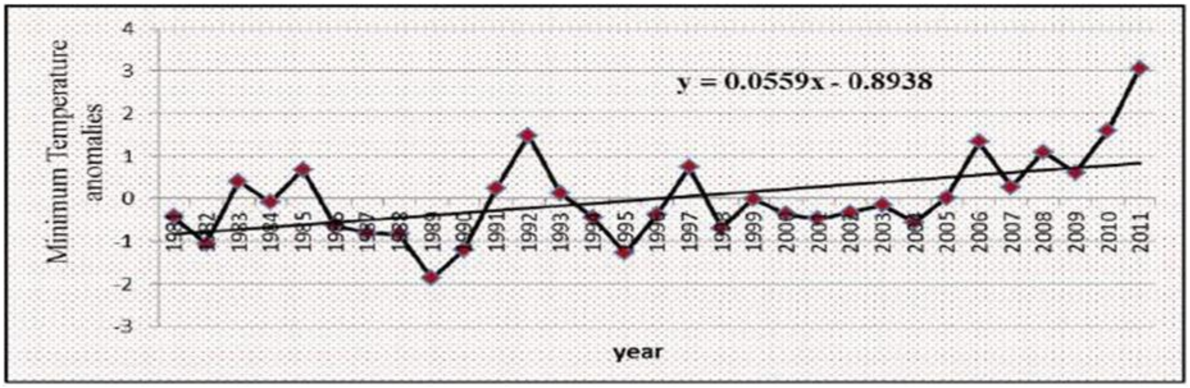


FIG. 12. **Year to year variability of annual minimum temperature and trend over Borana zone expressed in temperature.**

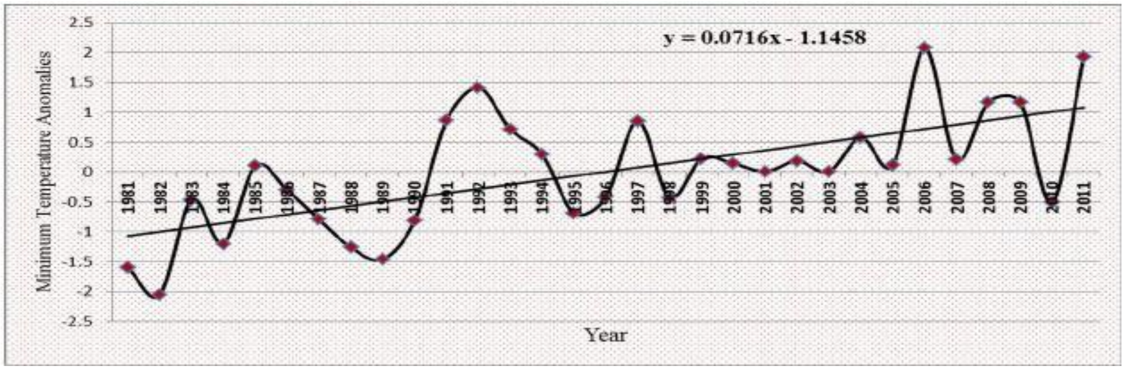


FIG. 13. **Year to year variability of JJA seasonal minimum temperature and trend over Borana zone expressed in temperature.**

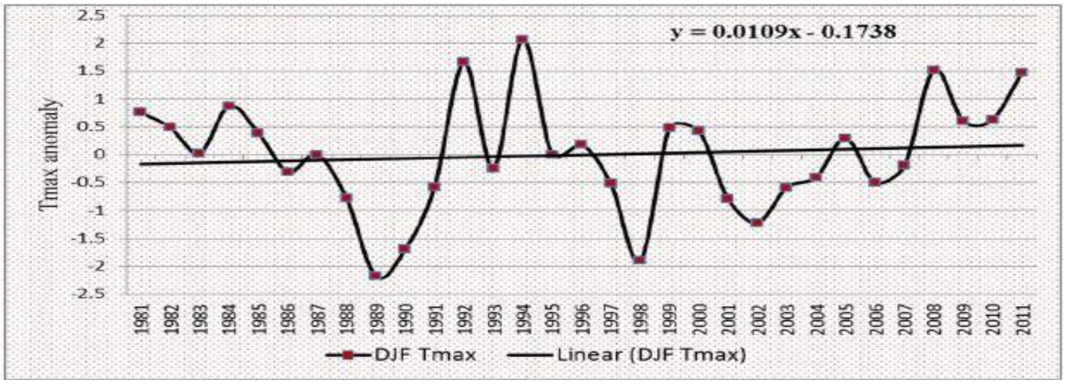


FIG. 14. **Year to year variability of DJF seasonal maximum temperature and trend over Borana zone expressed in temperature**

The JJA season minimum temperature showed remarkable temporal variability and steady increase in minimum temperature from 2004 to 2011 showed evidence of warming and hence progressive habitat dryness (FIG. 13). This season is commonly known as dry and cold season that hindering cattle production. Weak negative correlation that emerged between cattle population and rising temperatures could also indicate the effect of reduced water availability due to increased evaporative water loss and ultimately reduced forage availability as well as its quality. This seldom happened due to a reduced retention of green leaves by plants during the dry season.

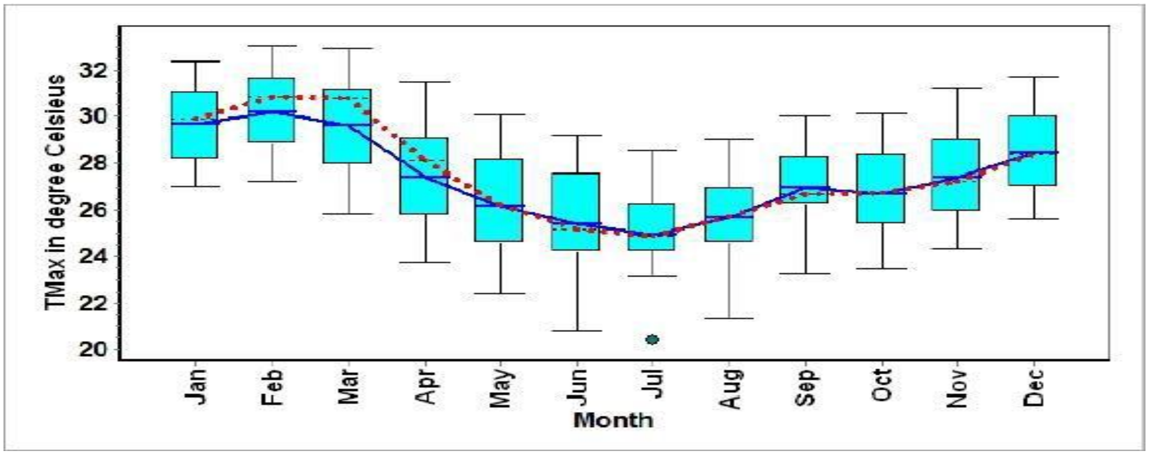


FIG. 15. **Box plot of mean monthly minimum temperature of Borana Zone where, blue Line represents mean and red line represents median.**

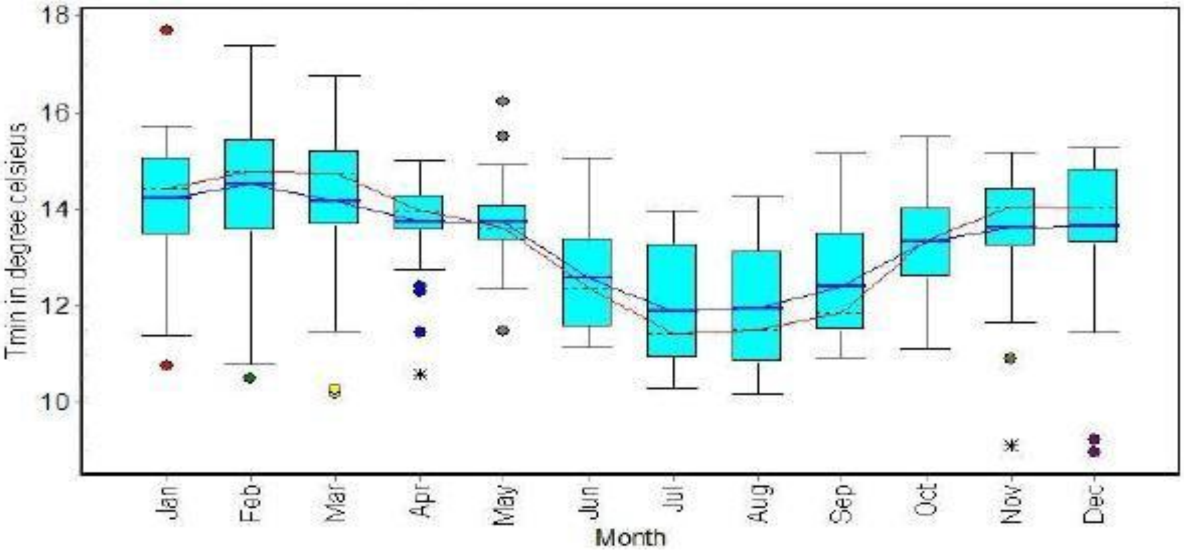


FIG. 16. **Box plot mean monthly maximum temperature of Borana Zone where blue solid line represents mean and red dot line represents Median.**

Homogeneous rainfall regime of Borana zone

From the global ocean, coarse scale of influence and particularly from the rainfall climatology point of view, it is often challenging to define such small areas into further homogeneous zones, without taking account of the interaction between the atmospheric circulation and detailed topography [43,44]. However, given the complexity of the climatic patterns in East Africa in general and Ethiopia in particular, it is not surprising to find large spatial variations in rainfall patterns in the study area FIG. 17. The Eigen values associated with each component represent the variance explained by that particular linear component. In addition, these values display the Eigen value in terms of percentage of variance explained (so, component 1 explains 81.969% and component 2 explains 7.68% of total variance). The remaining 11 components explain only 10.351%. The factors extracted accounted for 89.649% of cumulative whereas remain one covered 10.351% (TABLES 7 and 8).

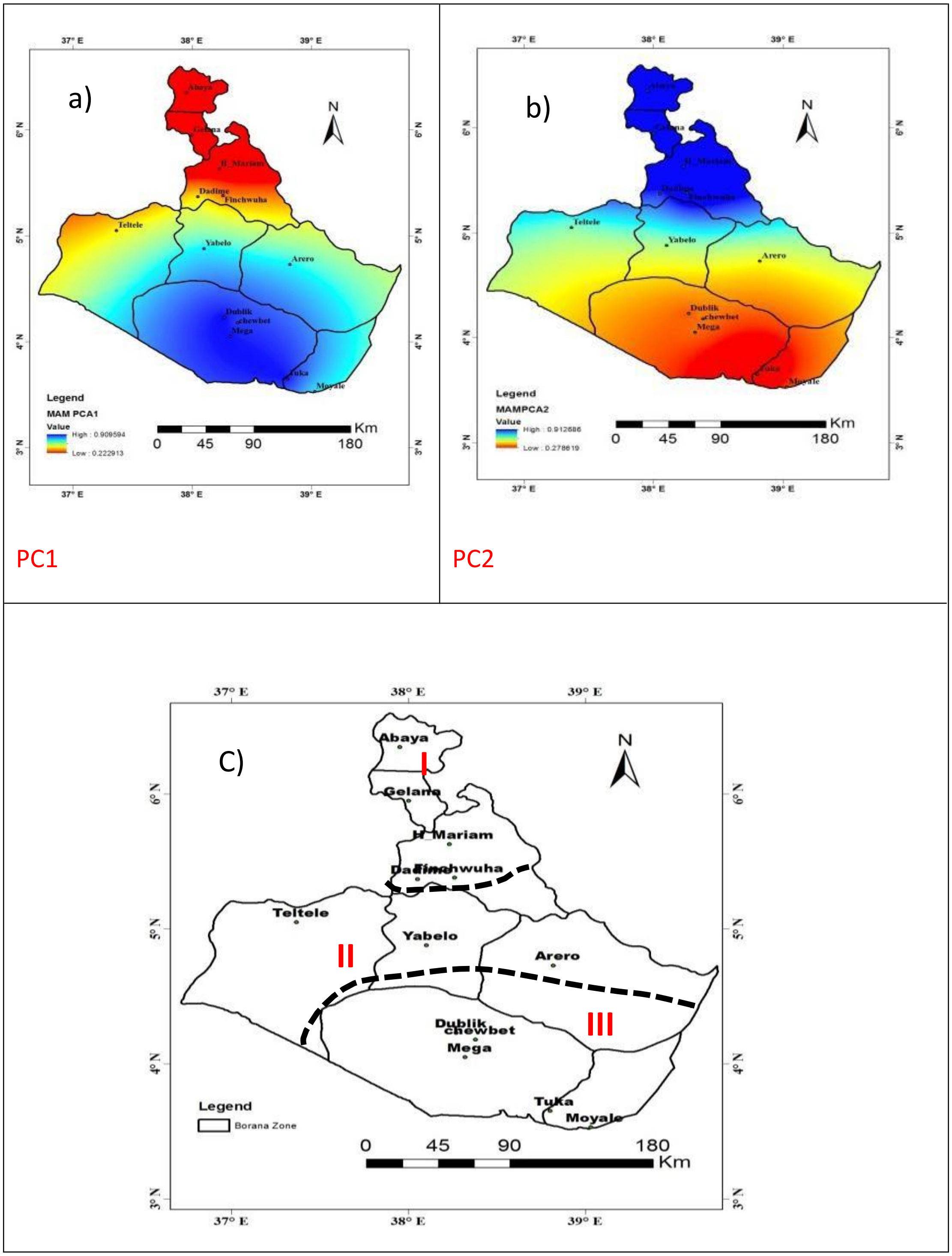


FIG. 17. **Three homogeneous rainfall zones in Borana Zone of Southern Ethiopia during MAM as defined by the principal component analyses.**

Relation between ENSO and rainfall at Borana zone

In recent decades, there has been a proliferation of statistical models for making extended-range forecasts of the state of the El Niño-Southern Oscillation (ENSO) phenomenon over lead-times of several seasons [45]. Because of ENSO variability is to a large extent the result of ocean atmosphere variability internal to the tropical pacific [46], skillful forecasts of central equatorial pacific sea surface temperature anomalies [45]. Correspondingly, [47] documented that ENSO predictability lead to potential predictability of seasonal climate over many tropical and some extra-tropical regions. Although the importance of ENSO to Ethiopian rainfall is being accepted and incorporated in the NMA’s operational forecasting policy more now than previously, it continues to be somewhat underweighted despite widespread documentation its importance [34,48].

TABLE 7. **MAM season total variance explained by each component of PCA.**

Component	**Initial Eigenvalues**			**Extraction Sums of Squared Loadings**			**Rotation Sums of Squared Loadings**		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	10.656	81.969	81.969	10.656	81.969	81.969	7.342	56.474	56.474
2	0.998	7.680	89.649	0.998	7.680	89.649	4.313	33.175	89.649

TABLE 8. **KMO and Bartlett's Test.**

Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.883
Bartlett's Test of Sphericity	Approx. Chi-Square	740.992
	df	78
	Sig.	0.000

The study aims to quantify the statistical relations between ENSO, and other oceanic and atmospheric phenomena and MAM, rainfall a practical objective being to develop models that skillfully anticipate rainfall anomalies prior an onset of rainy season, allowing for societal mitigation measures (TABLE 9).

TABLE 9. **Correlation between rainfall of (Zone I, Zone II, Zone III and MAM RF) and JFSST (Niño 3.4, Niño 4, Niño 3 and Niño 1+2) the same year (1983-2014).**

	Zone I	**Zone II**	**Zone III**	**MAM**	**NIN3.4**	**NIÑO 4**	**NIÑO3**	**NIÑO1 +2**
Zone1	1	0.890**	0.811**	0.939**	0.262	0.327	0.157	0.002
Zone2		1	0.946**	0.984**	0.283	0.299	0.205	0.096
Zone3			1	0.956**	0.341	0.348	0.257	0.115
MAM				1	**0.307**	**0.338**	0.214	0.073
NIN3.4					1	0.848**	0.958**	0.725**

NIÑO4						1	0.701**	0.360**
NIÑO3							1	0.873**
NIÑO1+2							1	

In Borana zone, during long rainy season La Niña event suppresses the main rainy season of the zone whereas El Niño enhanced the main rainy season of Borana zone (FIG. 18). Among ENSO regions Niño 3.4 and 4 indices have significant correlation with long rain over Borana zone (TABLE 9). As indicated in TABLE 8, all Niño region indices had shown better correlation with Zone III during MAM season than Zone I and Zone II while among Niño indices Niño 1+2 was not showed significant correlation with all three Zones during main rainy season. The association of MAM rainfall with ENSO in early pre-MAM month January is strong, and increases as the time of the ENSO state approaches the beginning of the rainfall season.

In particular, positive correlations are found between MAM total rainfall and Niño 3.4 SST over all Borana zone. However, better positive correlation was found between MAM total rainfall and Niño 4, which is statistically significant (>0.338). The high Niño 3.4 and 4 SSTs in January could be due to an El Nino that matured earlier and would likely dissipate before March tend to start opposite phase of El Nino, La Nina. However, the emerging of El Nino phase in January usually strengths and persists during pre-season and in-season enhance the Borana zone rainfall whereas persistence of La Nina prolong rain and concurrent causes declining of Borana zone rainfall. A time series of the Borana zone MAM rainfall average, which was computed for 1983-2014 and standardized by 1983-2012 rainfall statistics, has shown in FIG. 19. Overall, abundant rainfall tends to occur during La Nina (El Nino) long rain season (MAM) (TABLE 10).

For instance, around 60% decline in Borana rainfall during long rain season is associated with La Nina whereas 40% of rainfall deficient associated during El Nino and Neutral years (FIG. 19). However, El Nino events enhance long rain of Borana during MAM season whereas La Nina events suppressed the main rainy season of the zone (FIG.18a-18c).

The strengths of linear relationship between Zone I, Zone II, Zone III MAM rainfalls and the Nino 3.4 SST index for individual months from January, February and mean JF was shown in TABLE 9 and the correlations are about 0.33, 0.28 and 0.31, respectively during the preceding months of the long rainy season.

Canonical correlation analysis (CCA)

A comparison between matched pairs of observed rainfall anomaly and the cross validated anomaly prediction values have been made by CCA was employed to develop skillful seasonal rainfall model. It is assumed that once sound a prediction model has been developed and cross-validated giving high forecast skill, then the candidate model can be operationally used in forecasting future values of the predictands, based on the future observations of the predictor variable [46]. As depicted TABLE 11, different oceans SSTs were strongly related to the rainfall patterns of the different months, as well as different zones. The tropical SST predictors were used to train seasonal-rainfall models for different zone. For instance, mean JF

SST’s were selected for developing suitable prediction models for MAM season. For clarity, the prediction results would be discussed zone wise as follows:

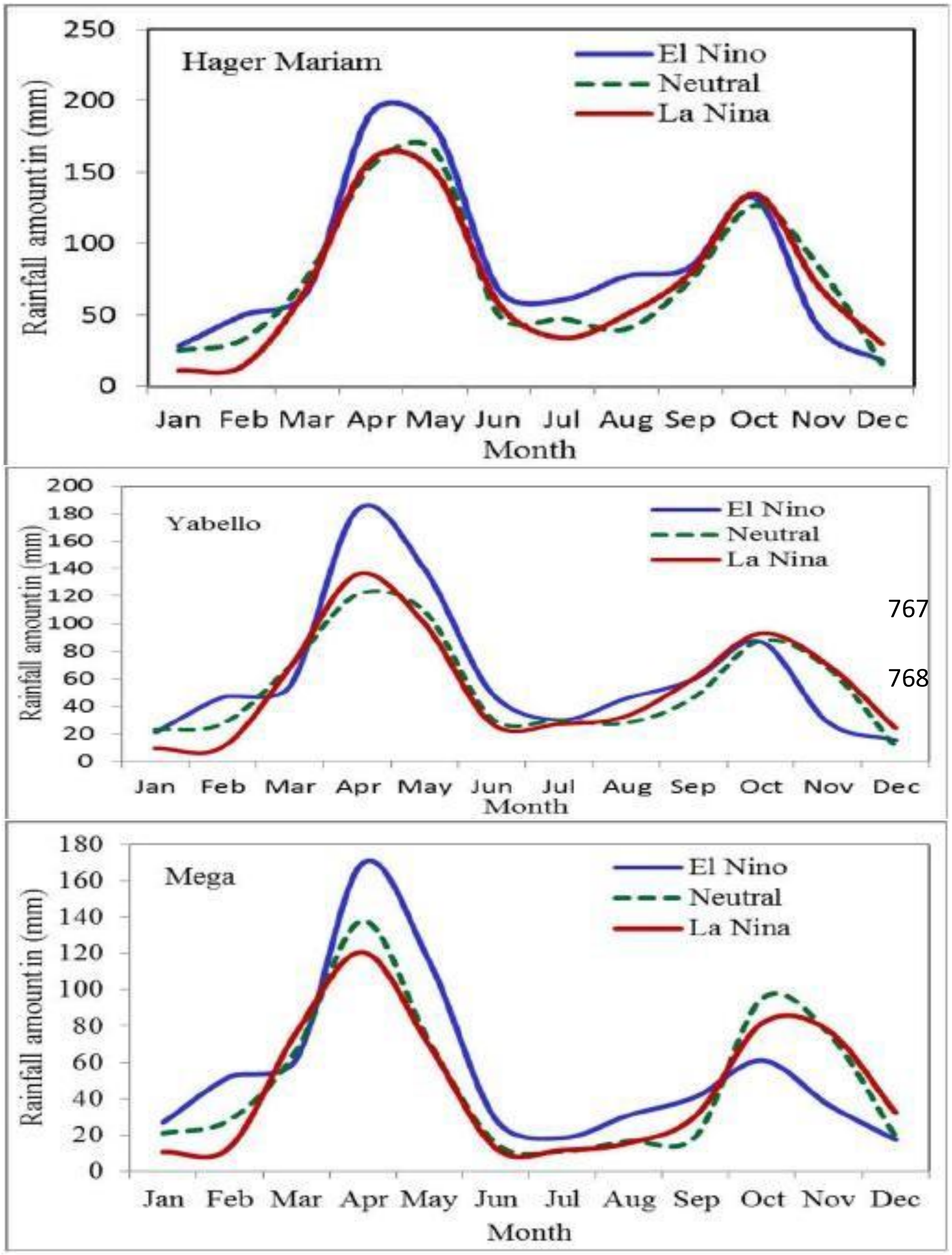


FIG. 18. **Seasonal march of mean monthly rainfall amount (mm) composited when MAM season is classified as El Niño, La Niña, or neutral, for three stations located in the north, central, and southern portions of Borana Zone.**

TABLE 10. **Correlation between Zone I, Zone II, Zone III, MAM rainfall and preceded monthly Nino 3.4SST.**

Preseason	**Jan**	**Feb**	**JF**	**Zone 1**	**Zone 2**	**Zone 3**	**MAM**
Jan	1	0.980**	0.996**	0.282	0.306	0.350*	0.325
Feb		1	0.994**	0.234	0.251	0.327	0.281
JF			1	0.262	0.283	0.341	0.307
Zone1				1	0.890**	0.811**	0.939**
Zone2					1	0.946**	0.984**
Zone3						1	0.956**
MAM							1

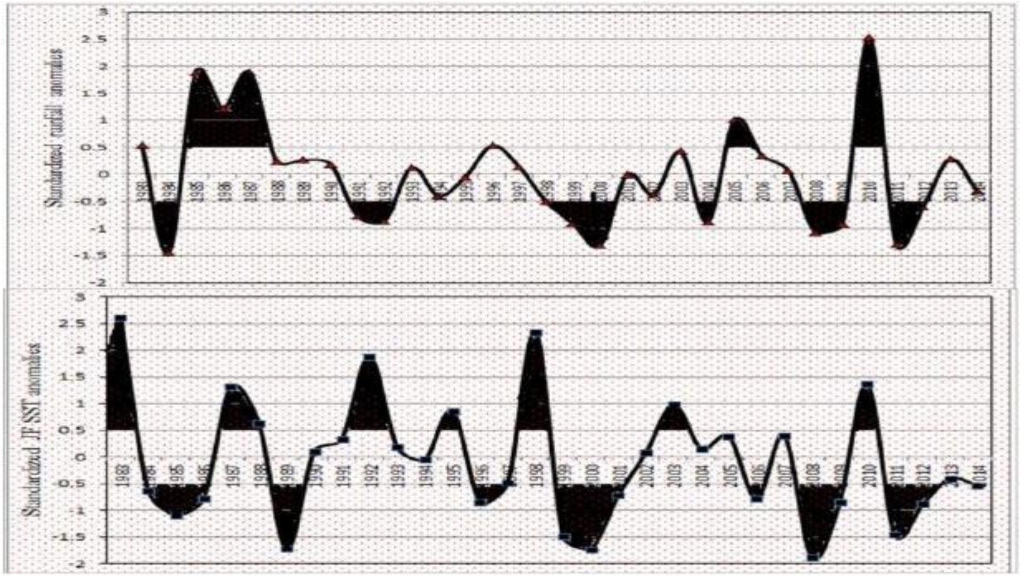


FIG. 19. **Standardized MAM rainfall anomalies of (top) all Borana Zone rainfalls and (bottom) those of Niño-3.4 SST for 1983-2014. Correlation among the two is 0.31.**

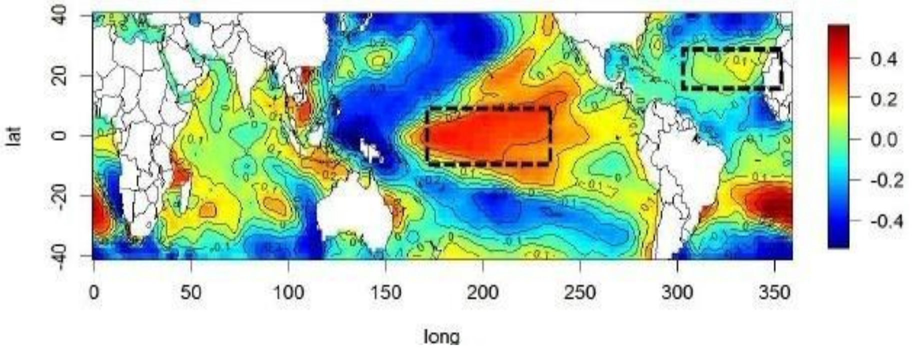
TABLE 11. **Prediction models for MAM rainy season for Borana Zone.**

Prediction Model	**R**	**R^2**	**P<**
Zone IMAM = -0.145*PNA- 0.597*NAO+ 0.162*Nino 3.4	0.76	0.57	0.05
Zone IIMAM=-0.731*NINO4-0.252*WPAC-0.903*NAO+0.490*NPAC	0.85	0.73	0.01
Zone IIIMAM= -1.036*NATL -0.165*WP-0.652*NAO	0.73	0.53	0.05

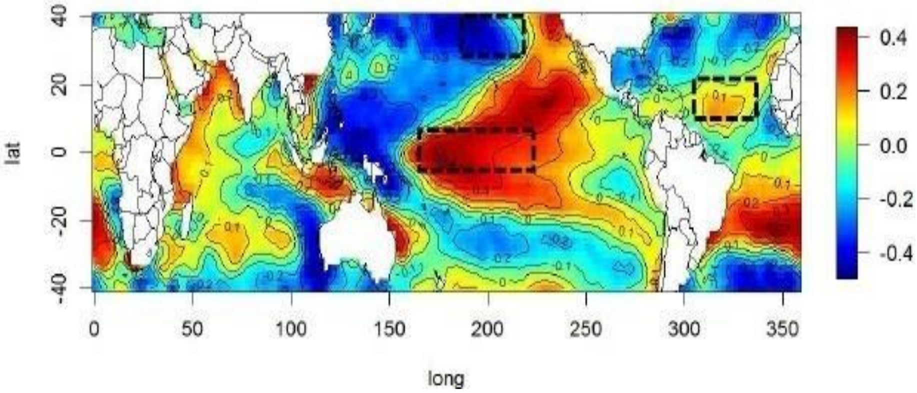
Historical records of SSTs over 1983-2004 are used to develop the model. The resulting model used three predictors such as Pacific North America (PNA), North Atlantic Oscillation (NAO) and Nino 3.4SST (FIG. 20). This model results in a highly significant multiple R2 of 0.57. The model equation, with standardized variables are for Zone I, Zone II and Zone III during MAM season see model equation in the (TABLE 11). The model explains 57% of the total variance of Zone I seasonal rainfall (R=0.76) and R^2 =0.57). The time series of hindcasts from Zone I rainfall and the multiple regression model has shown in FIG. 21a.

The distribution of spatial correlation with mean of JF SSTs affect the MAM season. During this season, strongest feature in FIG. 20, mean of JF SST is ENSO related with positive (negative) ENSO phase associated with low (high) seasonal rainfall. The correlation patterns over Nino 3.4, PNA and NAO were showing strong relationship with Zone I rainfall during MAM season whereas central Atlantic and Indian Oceans do not show strong features. Correspondingly, from FIG. 20 correlation patterns over the North Atlantic (NATL), West Pacific (WP) and NAO have revealed strong relationship JF SST and Zone III rainfall during MAM season. A weak positive correlation was shown over Indian Ocean while the weak negative over seen over South Pacific Ocean.

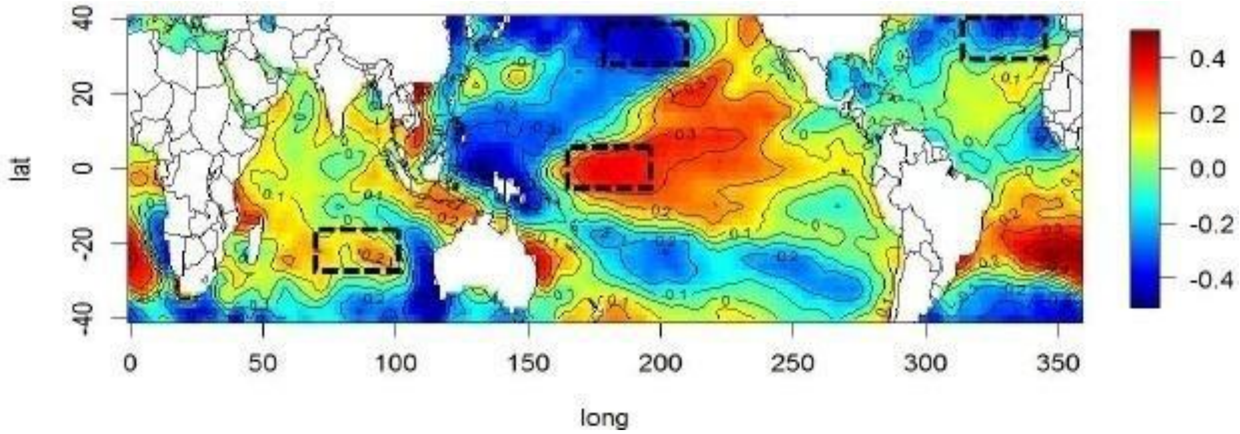
Generally, as described in FIG. 20 NAO has highly negative correlation with MAM rainfall for all three homogenous rainfall regimes. While, JF Nino 3.4 and 4 SST are positively correlated with MAM rainfall, which enhances the rainfall for Borana zone.



a) Zone I weighted MAM RF anomaly correlation with JF SST from (1983-2014)



b) Zone II weighted MAM RF anomaly correlation with JF SST from (1983-2014)



c) Zone III weighted MAM RF anomaly with JF SST from (1983-2014)

FIG. 20. **Spatial correlation between MAM seasonal rainfall and sea surface temperature (SST).**

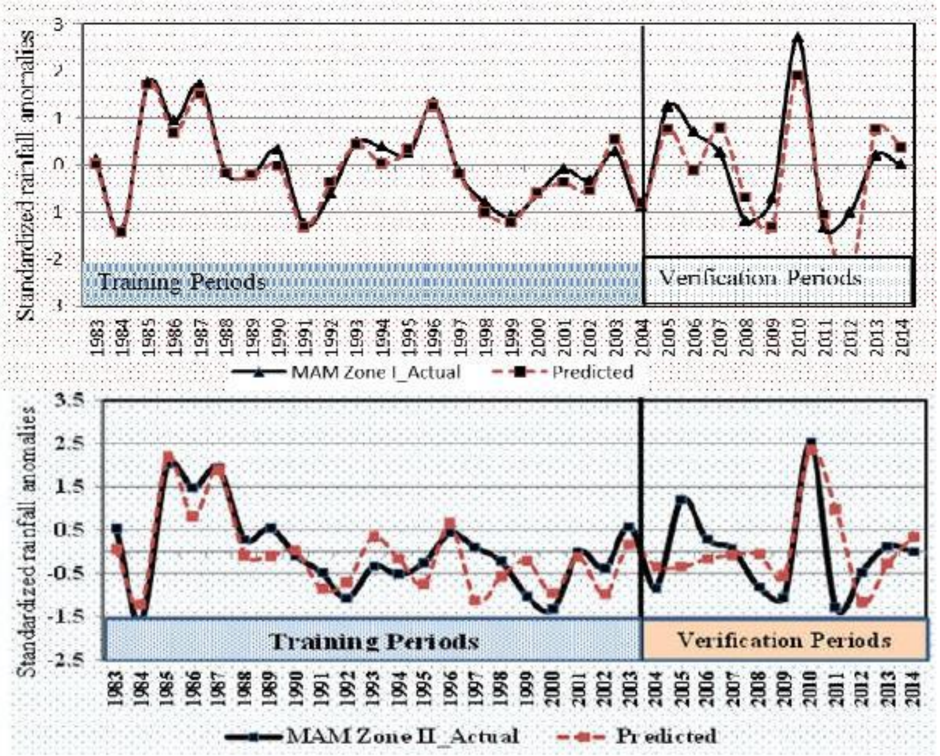


FIG. 21. **Time series of mean JFSST anomalies (°C) as observed for the periods 1983-2004 and MAM predicted rainfall were available for 1983-2014, whereas the multiple linear regression models are built based on 1983-2004 and validated for the remaining period.**

Discussions and Conclusions

In Borana zone of southern Ethiopia, the long rainy (MAM) season is the main season, which is very essential for different accomplishments. As result of rainfall and temperature trend analysis indicated, at present Borana societies faced to climate variability such as a declined of rainfall in amount and raised in temperature, which also adversely affected pastoral livestock production through indirect impacts on pasture growth, water availability and disease distributions. The pastoralists of Borana used and relied on traditional climate prediction to reduce in advance climate-related hazards that recently decline due to climate variability. In recent years however, as localized meteorological monitoring systems have expanded, pastoralists are willing to utilize climate-based early warning for early action. This study examined, localized seasonal climate prediction method and applies in proactive reducing climate-related hazards on livestock productivity over Borana zone and plan user-interface climate package for the pastoral community of Borana zone.

In all parts of Borana zone, arid and semi-arid lowland and high rainfall variability are strong inducing prolonged droughts. This study examines the seasonal and annual rainfall analysis by using thirty-two years data. The recent declining in the long seasonal rainfall happened predominantly because of the substantial decline in April and May rainfall over Borana zone. Inter annual variation in seasonal rainfall was better indicator of drought occurrences than variation in the total annual rainfall as droughts often resulting from sequential deficits in the long and short rain. The study further specified that main cause of drought over Borana due to declining in long rainy (MAM) season. The results further showed as well that rainfall is highly variable, especially in the arid and semi-arid Borana zone, and unreliable for rain-fed agriculture and livestock production.

Seasonal patterns as generated from the standardized anomalies of rainfall revealed that the droughts mostly occurred sequentially due to the failure in the long and short rain. As a time, series of standardized rainfall indicated clearly indicated droughts occurred during 1984, 1992, 2000, 2004, 2009 and 2010/11 directly associated with failures of long rainy season. The study further showed that declining in cattle populations were associated with an analogous underlying trend in rainfall and wider range of its variability. The result of this study revealed that zonal temperatures have shown increasing trends on monthly, seasonal and annual time scales.

During short, dry and cold (JJA) season, the minimum temperature was highly variability with an increasing trend. Indeed, it has been increasing by about 0.560 per ten years. As the trend line clearly revealed that there has been a warming trend in the annual minimum temperature over the past 31 years with the value of about 0.7°C per decade.

Using principal component analysis, the main rain (MAM) season of Borana zone were classified into three homogeneous rainfall regimes. Wide scale global and regional atmospheric and oceanic bodies have strong link with these homogeneous rainfall regimes in different seasons. This study identified that El Nino enhances while La Nina suppresses the long rain of Borana zone.

Multivariate statistical techniques have applied to analyze and predict seasonal rainfall patterns using preceding monthly mean global sea surface temperatures and other related predictors data. Lag relationship between ENSO and zonal rainfall revealed that ENSO has skillful predictability for long rainy season of Borana zone. Based on this analogy, this study established possible ways to use ENSO states and its direction and rate of evolution, as a simple statistical precursor MAM rainy season.

In generally, statistical seasonal climate prediction method skillfully predicted seasonal rainfall of Borana zone. It was confirmed that climate prediction is one of the most imperative proactive means to minimize climate-related hazards, such as droughts and disease in order to increase both quantity and quality of livestock production in Borana zone. Accustomed to use of seasonal climate forecasting can in fact increase awareness, leading to recovering social, economic and managing products within livestock production systems. In addition, seasonal climate prediction is one of many risk managing tools that play an important role in managing livestock decision making. Employing the use of reliable and up-to-dated seasonal climate forecast enable communities in order to recover social and economic wellbeing, managing products with in livestock production by using scientific weather/climate forecast/prediction amongst Borana pastoralists in advance.

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