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Rangeland water requirement satisfaction index under rainfall variability and predicting future rainfall scenarios: implication for availability of feed resources

Hassen M. Ahmed[1,4*], Zewdu K. Tessema[1], Adugna Tolera[2] and Diriba Korecha[3]

Abstract

Introduction: Rangeland ecosystems provide multiple ecosystem services, including feed resources for wild and domestic herbivores in semi-arid areas. However, under the ever increasing environmental changes, the impact of rainfall variability on the productivity and vegetation dynamics of rangelands are the great challenges that pastoral community are facing today. As a result, the potentials of most rangelands in semi-arid ecosystems affect the livestockproduction. Therefore, we studied the interconnections between the long-term rainfall variation and the rangeland Water Requirement and Satisfaction Index (WRSI) in Mieso, Jigjiga, and Shinile districts under pastoral conditions of Ethiopia.

Methods: The base period rainfall data (1984–2015) was obtained from the National Meteorological Agency of Ethiopia, whereas the future rainfall trend was predicted using MarkSim software (Representative Concentration Pathways 4.5 GHG concentration trajectory). Mann-Kendall's statistical tests, coefficient of variation, LEAP software (version 2.61), and Minitab Software (version 15) were used to assess the relationship between rangeland WRSI and long-term rainfall variability.

Results: The result indicated that mean annual rainfall anomaly had strong positive correlation with rangeland WRSI in Mieso ($P < 0.05$), Jigjiga ($P < 0.001$), and Shinile ($P < 0.001$) pastoral areas. Similarly, short and long rainy seasons had positive association ($P < 0.001$) with rangeland WRSI, especially in Jigjiga and Shinile pastoral districts. The base period rainfall as well as the predicted annual rainfall showed variability in amount and distribution in all studied districts in pastoral areas of Ethiopia.

Conclusions: The mean annual rainfall anomaly is correlated with the rangeland WRSI. Moreover, the future rainfall trend analysis indicated that variability of rainfall would be expected in between the years 2020–2049, 2040–2069, and 2070–2099. Thus, the future rainfall variability would limit future rangeland WRSI under pastoral conditions of Ethiopia. Based on our study, we suggested establishment and implementation of early warning systems to reduce the likely impact of rainfall variability on future rangeland potential in dry lands under the pastoral production systems in eastern Ethiopia.

Keywords: LEAP software, Pastoralist, Rangeland water requirement, Trend analysis

* Correspondence: hassenahmed211@gmail.com
[1]School of Animal and Range Sciences, College of Agriculture and Environmental Sciences, PO Box 138, Dire Dawa, Ethiopia
[4]School of Animal and Range Sciences, College of Agriculture and Environmental Sciences, Haramaya University, PO Box 1632, Dire Dawa, Ethiopia
Full list of author information is available at the end of the article

Introduction

Rangeland ecosystems provide multiple ecosystem services, including feed resources for wild and domestic herbivores in semi-arid areas (Eldridge and Delgado-Baquerizo 2016), in addition to reducing the concentration of atmospheric carbon dioxide (IPCC 2007). However, under the ever increasing environmental changes, the impact of rainfall variability on the productivity and vegetation dynamics of rangelands and availability of water both for human and livestock are the great challenges that the pastoral communities are facing at present in semi-arid areas of Ethiopia (Kassahun et al. 2008). As a result, the carrying capacities of most rangelands in arid and semi-arid ecosystems do not sustain livestock production (IPCC 2014; Shine and Dunford 2016).

Previous studies highlighted the connection between rainfall variability and vegetation cover, as well as rangeland greenness in semi-arid ecosystems. For instance, according to Adler and Levine (2007), under the ever increasing environmental changes, vegetation productivity, basal cover, and species composition in arid and semi-arid rangelands were strongly associated with rainfall availability. Moreover, the alteration of rainfall distribution associated with long-term climate change/variability is expected to influence plant productivity and species diversity in semi-arid areas (Cheng et al. 2011). As a result, the rangeland vegetation cover and its potential productivity could be limited by the long-term rainfall variability and its distribution in arid and semi-arid ecosystems (Cheng et al. 2011). Accordingly, for the sustainable utilization and management of rangelands, as main feed resources for both domestic and wild herbivores, monitoring of climatic risk through the development of rangeland water requirement and satisfaction index is very crucial in arid and semi-arid ecosystems (Peter and Sandro 2012). Therefore, rangeland WRSI is defined as the amount of water required to replenish water that is lost through evapotranspiration (ET) processes, and it is calculated using a water stress index scheme to determine whether a given rangeland vegetation has sufficient water to achieve its potential yield or not in a particular season (Peter and Sandro 2012; Senay et al. 2011).

Although several studies have been conducted on rangeland vegetation and productivity in semi-arid ecosystems in Ethiopia (e.g., Kassahun et al. 2008; Angassa and Oba 2007, 2010; Tessema et al. 2011; Angassa et al. 2012; Angassa 2014; Bikila et al. 2014, 2016; Bikila and Tessema 2017), information on the impact of long-term rainfall variability on rangeland WRSI in semi-arid areas of Ethiopia is lacking. Therefore, studying the interconnection between long-term rainfall variability and rangeland WRSI is very crucial to predict the impact of rainfall variability on the rangeland composition and productivity in arid and semi-arid ecosystems (Cheng et al. 2011). It is also important to study the relationships between the current rainfall amount and distribution with the expected future rainfall scenarios in semi-arid ecosystems to minimize the risks occurred on rangeland vegetation and livestock production as a result of rainfall variability (Thornton et al. 2009). Thus, this can be addressed through analyzing the current rainfall data with the future rainfall scenarios in relation to rangeland WRSI at ground level, as the information is very useful to manage rangelands during critical rainfall variability in arid and semi-arid ecosystems. Therefore, we studied rangeland WRSI using long-term mean annual rainfall with predicting future rainfall scenarios in Mieso, Jigjiga, and Shinile districts under the pastoral conditions of Ethiopia.

Methods

Description of the study areas

The study was conducted at Mieso, Jigjiga, and Shinile districts of eastern Ethiopia representing high, medium, and low rainfall distribution, respectively (Fig. 1). The study districts were selected based on their rainfall distribution and variability during the short and long rainy seasons, accessibility of the rangelands; fluctuation in livestock feed resources availability, frequency of drought, livestock potentials, and degradation of rangelands. Food security is a major challenge in these areas as climate shocks and rainfall variability have reduced the contribution of livestock production to pastoral livelihoods in these districts.

The average annual rainfall of Mieso, Jigjiga, and Shinile were 721 mm (coefficient variation; CV = 24.2%), 606 mm (CV = 30.8%), and 444 mm (CV = 31.5%; 1984–2015), respectively. The mean annual temperature of Mieso, Jigjiga, and Shinile were 22.5, 18, and 26 °C, respectively, (1984–2015). Under normal condition, Mieso received highest rainfall amount during long rainy season from June to September, whereas the short rains prevailed from March to April. In Mieso, the dry season sometimes extended from October to May when the short rainy season failed. On the other hand, Jigjiga and Shinile districts have bimodal rainfall, with short rainy season occurred from March to May, and followed by the main rainy season from July to late September. Rainfall occurs only for few months' in the study districts, and thus dry conditions with highly variable rainfall prevail during most of the year. As a result, recurrent drought is a major problem in the study districts. Topographic orientation of the study areas varied from typical lowlands to mid altitudes. Hence, the altitude of Mieso district ranged between 823 and 2475 m above sea levels (Aklilu et al. 2014) and altitudinal variation in Jigjiga and

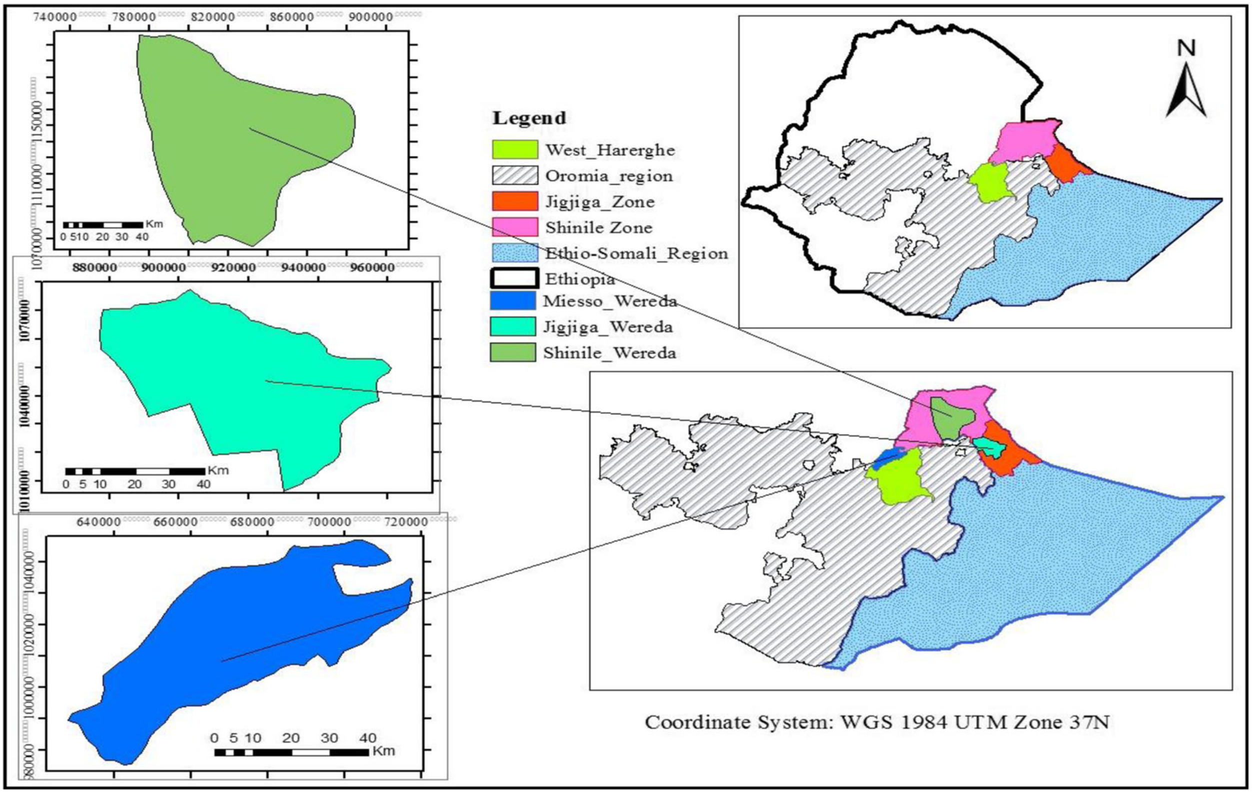

Fig. 1 Geographical location of the study districts; Mieso, Jigjiga, and Shinile in eastern Ethiopia

Shinile ranged between 500 and 1600 m above sea level. Agro-pastoralism is the dominant agricultural practice in Mieso and Jigjiga districts, while pastoralism is predominant in Shinile district. In all the study districts, rangeland is the primary sources of feed for livestock.

Data source and sampling techniques

The gridded (10 km × 10 km) rainfall data from 1984 to 2015 were obtained from the National Meteorological Agency of Ethiopia (NMA) as the World Meteorological Organization (WMO) recommended >30 years is a classical period for studying the rainfall variability statistics, which is used to define climate (IPCC 1999). Accordingly, rainfall data collected over 30 years were organized into seasonal and annual basis. Then, the seasonal and annual rainfall were plotted against their long-term means and fitted with trend lines to observe the overall tendency of each dataset. Moreover, the spatial and temporal rainfall and rangeland WRSI pattern over the three study districts were processed using The Livelihoods, Early Assessment and Protection (LEAP) software (version 2.61; Peter and Sandro 2012).

The LEAP system is an innovative early warning––early action tool, developed in 2008 by World Food Program (WFP) (Hoefsloot 2010). The software uses agrometeorological data to monitor and estimate crop and rangeland productions. Satellite rainfall estimates have been used as input to a geospatial crop and rangeland water balance model that evaluates the availability of moisture to a crop or rangeland vegetation according to its requirement over the course of the growing season. Thus, the WRSI is the ratio of actual crop evapotranspiration to the rainfall amount that would occur with a normal water supply. A long-term average of potential evapotranspiration in combination with soil water holding capacity and water balance data was used as input to calculate the rangeland WRSI. The potential evapotranspiration (PET) and actual evapotranspiration (AET) data for a reference crop is calculated according to the Penman-Monteith equation (Shuttleworth 1992). Under LEAP model, rangeland is included as part of the crop basket, and thus, the parameters used in the crop database are also applied for rangelands. However, in the case of rangelands, the crop coefficient value of one (1) is considered with the assumption that most rangelands under the pastoral systems are expected to receive WRSI values >80% during a normal year according to Senay et al. (2011). The rangeland WRSI is computed as a continuous calculation based on five dekade cycle lengths using a crop coefficient value of one and an assumed water holding capacity of 50 mm per growing season because poor supply of water will not entirely satisfy the rangeland vegetation water demand (Mukhala and Hoefsloot 2004). Therefore, rangeland WRSI was calculated as the ratio of the actual evapotranspiration to the seasonal rangeland water requirement.

$$\text{WRSI} = \frac{\text{AET}}{\text{WR}} \times 100 \tag{1}$$

WR = PET ∗ Kc, where rangeland WR is water requirement, from Penman-Monteith equation (Shuttleworth 1992), PET is potential evapotranspiration, and AET is actual evapotranspiration, representing the actual amount of water withdrawn from the soil water reservoir, and K_c is crop coefficient during the growth stage of rangeland vegetation (Senay et al. 2011).

Statistical analyses

Analysis of current rainfall patterns

Mann-Kendall's test was used to assess the current and future mean annual rainfall trend for Mieso, Jigjiga, and Shinile districts for the time period between 1984 and 2015 using XLSTAT software. Mann-Kendall's test is a non-parametric method, (i.e., does not rely on any assumptions on the distributions of the two populations under comparison) which is less sensitive to outliers and test for time sequential order (Partal and Kahya 2006; Yenigun et al. 2008; Gebre et al. 2013; Tsegaye et al. 2015). The Man-Kendall's test statistics is given as:

$$S = \sum_{i-1}^{n-1} \sum_{j=i+1}^{n} \text{Sgn}(xj - xi) \tag{2}$$

where, S is the Mann-Kendall's test statistics; x_i and x_j are the sequential rainfall or temperature values in the year i and j ($j > i$), and n is the length of the time series. The Sgn ($x_j - x_i$) is an indicator function that results in the values −1, 0, or 1, where $j > i$ and it is calculated as:

$$\text{Sgn}(xj - xi) = \begin{pmatrix} +1 & \text{if} & xj - xi > 0 \\ 0 & \text{if} & xj - xi = 0 \\ -1 & \text{if} & xj - xi < 0 \end{pmatrix} \tag{3}$$

The variance (Var) of S, for the situation where there may be ties (that is equal values) in the x values, is given by:

$$\text{Var}\ (S) \frac{1}{18}(n-1)(2n+5) - \sum\nolimits_{i=1}^{m} \text{ti}\ (\text{ti}-1)(2\text{ti}+5)) \tag{4}$$

where m is the number of tied groups in the data set and it is the number of data points in the ith tied group. For n larger than 10, Z_{MK} approximates standard normal distribution (Partal and Kahya 2006; Yenigun et al. 2008; Karpouzos et al. 2010), and it is used to evaluate whether the trend is statistically significant or not, and it is computed as:

$$\text{Zmk} = \begin{matrix} \frac{S-1}{\sqrt{\text{Var}\ (S)}} & \text{if} & S > 0 \\ 0 & \text{if} & S = 0 \\ \frac{S+1}{\sqrt{\text{Var}\ (S)}} & \text{if} & S < 0 \end{matrix} \tag{5}$$

The Sen's estimator of slope: The test is applied where the trend is assumed to be linear (Gebre et al. 2013). It is not affected by missing data and outliers (Karpouzos et al. 2010). Then, the slope (change per unit time) was calculated as:

$$Q = \frac{xj - xi}{i - j} \text{ for } i = 1 \ldots n \tag{6}$$

where, x_i and x_j are data values at times i and j ($j > i$), respectively. The median of these n values of Q is Sen's estimator of slop. Based on the above procedure, trends of current and future climate elements (rainfall, temperature) were determined.

Analysis of rainfall variability

Rainfall variability and its characteristics were analyzed using coefficient of variation; CV (Ayalew et al. 2012; Gebre et al. 2013; Tsegaye et al. 2015), and it is calculated as: $\text{CV} = \frac{\text{SD}}{X} \times 100$, where CV is coefficient of variation, SD is standard deviation and X is the long-term mean. The CV values categorized as less variability (<20%), moderate variability (20–30%), and high variability (>30%) (ABM 2010). Linear regression analysis using SAS software (SAS 2008 Ver. 9.1) was used to determine the association between rainfall variability and rangeland WRSI during the study.

The future climate scenario analysis

The World Climate Research Program's (WCRP's) Coupled Model Inter-comparison Project phase 5 (CMIP5) developed outputs from many General Circulation Models (GCMs). Four Representative Concentration Pathway (RCPs) which are greenhouse gas (GHG) concentration trajectories are recommended by IPCC (2013) to downscale the future rainfall. Each of RCPs defines the trajectory of the alteration or change in the net irradiance (Watt per square meter = Wm^{-2}) of the tropopause due to an increase in the concentration of GHG and other forcing agents for the year 2100. In RCP 2.6, GHG concentrations rise in the 2050 and then decline so that the forcing (extra energy trapped in entire atmosphere) will be 2.6 Wm^{-2} in the year 2100. The peak forcing is 3 Wm^{-2} of the twenty-first century, and this is a rapid mitigation trajectory of concentration rise. The RCP4.5 trajectory selected for our downscaling, the

GHG concentrations rise with increasing speed until the forcing is 4.5 Wm^{-2} in the year 2100 and the future period during which global annual GHG emissions are expected to peak around 2040. Thus, RCP 4.5 version was selected in our study due to its suitability for downscaling to those areas close to the Red Sea according to the recommendation of the Paris climate meeting. In contrast, in RCP6 trajectory, GHG concentrations rise with increasing speed until the forcing is 6 Wm^{-2} in the year 2100. This is a moderately high GHG of concentration rise. In RCP8.5, GHG concentrations rise with increasing speed until the forcing is 6 Wm^{-2} in the year 2100. This is a high trajectory of concentration rise. Hence, the data set in this experiment were model outputs from 17 GCMs used for the Fifth Assessment (AR5) of 4.5 Wm^{-2} RCP.

The climate record in our study contains the latitude, longitude, and elevation of the location and monthly values of rainfall, daily average temperature, and daily average temperature variation (Jones and Thornton 2013). It also included the temporal phase angle, that is, the degree by which the climate record is "rotated" in date. This rotation is done to eliminate timing differences in climate events, such as the seasons in the Northern and Southern hemispheres, so that analysis can be done on standardized climate data to identify and account for the lag phase between climate cycles. The climate record is rotated to a standard date, using the 12-point Fast Fourier transform, on the basis of the first phase angle which is calculated using both rainfall and temperature values. We used MarkSim software, which is suited for future weather generator and a program for pattern scaling of future climate simulations in Mieso, Jigjiga, and Shinile districts. The MarkSim-GCM software used latitude, longitude, and elevation of the study districts (Jones and Thornton 2013). For each district, data of future rainfall and temperature (2020–2099) were downscaled during our study. Moreover, future rainfall and temperature changes were analyzed for three-time slot-centered between 2020–2049, 2040–2069, and 2070–2099, and these values were compared with the trend and variability of the base period rainfall data (1984–2015).

Results

Annual and seasonal rainfall trend and variability

The Mann-Kendall trend analysis indicated that the annual and seasonal rainfall data have shown increasing and decreasing trend in our study districts (Table 1). For instance, in all study districts, the rainfall amount in short rainy season showed an increasing trend, whereas, the rainfall trends in long rainy season showed a declining trend over time in Jigjiga and Mieso districts, and an increasing trend in Shinile district (Fig. 1). There was high annual rainfall variability in all study districts. However, there were a higher rainfall variability in Jigjiga (CV = 30.8%) and Shinile (CV = 31.5%) districts than Mieso district, with a moderate rainfall variation (CV = 24.2%). There was also seasonal rainfall variability in all the study districts. Moreover, the rainfall variability was high during the short and long rainy seasons in all the study districts. In short rainy season, the rainfall variability at Mieso, Jigjiga, and Shinile were 31, 44.1 and 34.3%, respectively, whereas, in the long rainy season, the rainfall variation at Mieso (CV = 35.5%) and Shinile (CV = 40.9%) were also higher compared with the rainfall variability of Jigjiga (CV = 27.8%). However, the increasing and decreasing trends of rainfall were not significant ($P > 0.05$) in our study. The total amount of rainfall distribution in Mieso district was better than Jigjiga and Shinile, in which Shinile was found the driest district among the study districts. In addition, all of the study districts experienced bimodal rainfall cycle, where short rainy season rainfall accounts for 47.3, 49.8, and 43.9% of the total annual rainfall of Mieso, Jigjiga, and Shinile, respectively. The years 1984 and 2000 were found to be the driest years, while years 1996 and 2010 were found the wettest years in all the study districts (Fig. 2).

Response of rainfall variability to rangeland water requirement satisfaction index

In the last three decades, high to moderate rainfall variability was observed in Mieso, Jigjiga, and Shinile districts during our study. Moreover, Shinile district manifested unevenly coverage of annual rainfall in most of the rangeland areas. The computed statistical values revealed that rainfall distribution and rangeland WRSI

Table 1 Trends of annual rainfall and seasonal rainfall for the period 1984–2015 in pastoral, production systems of Mieso, Jigjiga, and Shinile districts of eastern Ethiopia

	Annual rainfall		Long rainy season rainfall		Short rainy season rainfall	
	Z_{MK} (ns)	Slope	Z_{MK} (ns)	Slope	Z_{MK}	Slope
Mieso	0.01	+0.53	−0.24	−8.66	0.27	6.62
Jigjiga	0.12	+8.73	−0.11	−4.16	0.22	8.62
Shinile	−0.01	−0.32	0.09	1.16	0.17	3.19

The mean seasonal and annual rainfall trend recorded during 1984–2015, increasing (+) or decreasing (−)
Z_{MK} is Mann-Kendall trend test, *Slope* (Sen's slope) is the change (mm)/annual/seasonal; *ns* is non-significant trend at 0.05

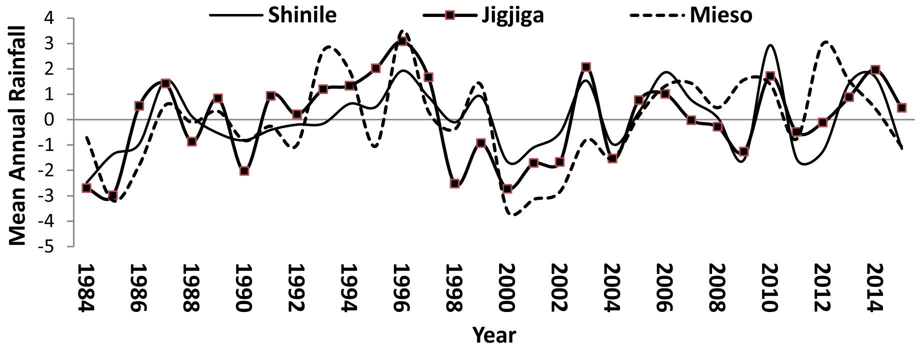

Fig. 2 Mean annual standardized rainfall anomalies and trend for Mieso, Jigjiga, and Shinile districts over the period of 1984–2015

values in most cases were positively associated ($P < 0.001$; Table 2). According to Fig. 2, the years 1984, 1998, 2000, 2002, and 2009 were the drought years, which attained below average amount of rainfall of the study districts. Moreover, the rangeland WRSI values of the study districts were also deviated negatively from the normal climatology. In contrast, the above mean annual rainfall amounts observed in 1996, 2006, and 2010 (Fig. 2) were substantially above the average rangeland WRSI values (Fig. 3). In most cases, there was a strong association ($P < 0.001$) between mean annual rainfall, seasonal rainfall, and rangeland WRSI values (Table 2).

Spatial and temporal patterns of rangeland WRSI in all study districts also showed that vegetation coverage was always higher during the long rainy season than that of the short rainy season. In general, the rangeland vegetation coverage varied in all the study districts as a result of rainfall variability during our study (Figs. 2 and 3).

Analysis of future climate scenarios

As compared to the amount of current rainfall, the annual rainfall would increase in all the study districts by years 2020–2049, 2040–2069, and 2070–2099 compared to current rainfall amount according to RCP 4.5 model scenario, except at Mieso in the year 2020–2049, which is estimated to decrease (Table 3; Fig. 4). The annual rainfall in the study districts is expected to increase by an average of 6.63, 4.64, and 3.05% in the years 2020–2049, 2040–2069, and 2070–2099, respectively, compared to the current rainfall amount. However, the magnitude of rainfall increase varied from districts to district during our study. For instance, annual rainfall in Jigjiga will be increased by 11.1, 0.72, and 0.56% in years 2020–2049, 2040–2069, and 2070–2099, respectively, compared to the rainfall of the base period (Table 3). Moreover, in Mieso district, the annual rainfall will be decreased by 2.6% in years 2020–2049 and increased by 3.8 and 2.7% in years 2040–2069 and 2070–2099, respectively. In Shinile district, the amount of annual rainfall will increase by 11.4, 9.4 and 5.9% in years 2020–2049, 2040–2069, and 2070–2099, respectively. The future annual rainfall is also predicted to be variable in all the study districts. Our result indicated that the annual rainfall at Mieso and Jigjiga were estimated as moderate variability, while at Shinile, it is expected as high variability. Moreover, the maximum temperature at Mieso, Jigjiga, and Shinile is expected to increase by an average of 1.8, 1.77, and 1.76 °C, respectively, in the year 2100 compared to the current maximum temperature in all the study districts. The minimum temperature is also estimated to increase at Mieso, Jigjiga, and Shinile in the year 2100 by 2.16, 2.05, and 1.94 °C, respectively.

Discussion

Rainfall variability and its response to rangeland water requirement satisfaction index

The spatial and temporal analysis of annual and seasonal rainfall of the study areas indicated that there was clear rainfall variability in all the study districts. Similar results were recorded in previous studies. For instance, Gebre et al. (2013) reported that the annual and seasonal rainfall were variable in northern region of Ethiopia. Ayalew

Table 2 Coefficient of regression for annual rainfall and seasonal rainfall (predictors) and rangeland WRSI values (dependent variable) for the period 1984–2015 in Mieso, Jigjiga, and Shinile districts of eastern Ethiopia

Study areas	Annual rainfall and rangeland WRSI	Short rainy season rainfall and rangeland WRSI	Long rainy season rainfall and rangeland WRSI
Mieso	0.35*	0.36*	0.09 ns
Jigjiga	0.80**	0.61**	0.69**
Shinile	0.87**	0.69**	0.76**

WRSI water requirement satisfaction index, *ns* non-significant at $P > 0.05$
*$P < 0.05$, **$P < 0.001$

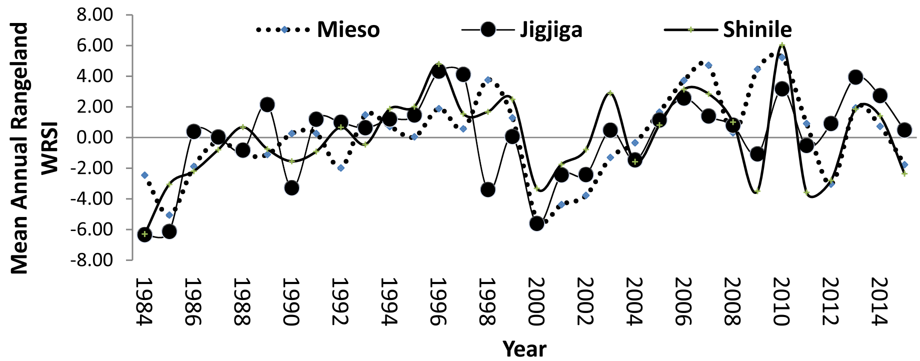

Fig. 3 Mean annual standardized rangeland WRSI values and trends for Mieso, Jigjiga, and Shinile districts over the period 1984–2015

et al. (2012) also confirmed the variability of rainfall in Amhara region of Ethiopia. This rainfall variability or fluctuation might be associated with the Sea Surface Temperature (SST) changes in the Atlantic and Pacific Oceans which leads to shift the rainfall direction and suppress rainfall distribution to Ethiopia (Korecha and Sorteberg 2013; Viste et al. 2013). Accordingly, such rainfall fluctuation affects the rangeland WRSI values in arid and semi-arid areas. The negative and positive values of rangeland WRSI are associated with the decrease and increase of rainfall distribution in our study. Moreover, the temporal and spatial analysis also identified positive association between mean annual and seasonal rainfall to rangeland WRSI, which might be associated with moisture that is needed for the growth and production of rangeland vegetation in semi-arid areas.

The high rangeland WRSI value was measured at Mieso and lower at Shinile districts, which could be due to the less annual and seasonal rainfall distribution at Shinile districts compared to others. From the annual quantitative analysis of vegetation coverage, there was variation in rangeland WRSI among years depending upon rainfall distribution. For instance, year 1984 was the lowest in rangeland WRSI; similarly lower vegetation coverage was recorded in year 2009 due to rainfall deviation from normal. This is possibly due to the availability of lower soil moisture. Significant positive association between rainfall and rangeland WRSI were recorded, which is an indication of strong relation between rangeland WRSI and rainfall intensity. There was also difference on the relative frequency of negative rangeland WRSI anomalies among the study areas, due to below normal rainfall distribution. Furthermore, the short and long rainfall in all districts also positively associated to their respective rangeland WRSI. Results from this study indicated that the trend of rainfall and rangeland WRSI showed a direct correspondence of anomalies in most years and in all study pastoral districts.

In most wet years, the rangeland WRSI value was above average, whereas in dry years, the rangeland WRSI value was deviated below average, indicating that rangeland WRSI mainly depend on rainfall amount. Therefore, in all the study districts, annual and seasonal rainfalls were positively associated to the corresponding rangeland WRSI. There has not been any study report on rangeland water requirement satisfaction index; hence, no comparison has made with any previous finding.

Predicted future climate scenarios

Expected future rainfall conditions revealed that the annual and seasonal rainfall most likely increase in all pastoral districts in the predicted years. On the other hand, there was a report by IPCC (2007) stated that there was increasing rainfall in parts of east Africa, which coincide with the study areas. In contrast, Tsegaye et al. (2015) reported a decrease in the future trend of annual rainfall in Adami-Tulu Jido-Kombolcha district of Ethiopia by using HadCM3 A2 and B2 scenarios. These different reports could be due to the types of GCM used to

Table 3 Trends of annual rainfall for the period of 2020–2049, 2040–2069, and 2070–2099 in pastoral production systems of Mieso, Jigjiga, and Shinile districts of eastern Ethiopia

Study areas	Annual rainfall (2020–2049)		Annual rainfall (2040–2069)		Annual rainfall (2070–2099)	
	Z_{MK} (ns)	Slope	Z_{MK}	Slope	Z_{MK}	Slope
Mieso	−0.06	−2.71	0.07	3.55	0.14	6.33
Jigjiga	0.319	14.28	0.03	0.61	0.08	1.79
Shinile	0.11	3.91	0.29	10.39	0.15	5.78

The mean annual rainfall predicted trend, a negative value represents a decreasing trend and positive values are an indication of increasing trends
Z_{mk} is Mann-Kendall trend test, *Slope* (Sen's slope) is the change (mm)/annual; *ns* is non-significant trend at 0.05

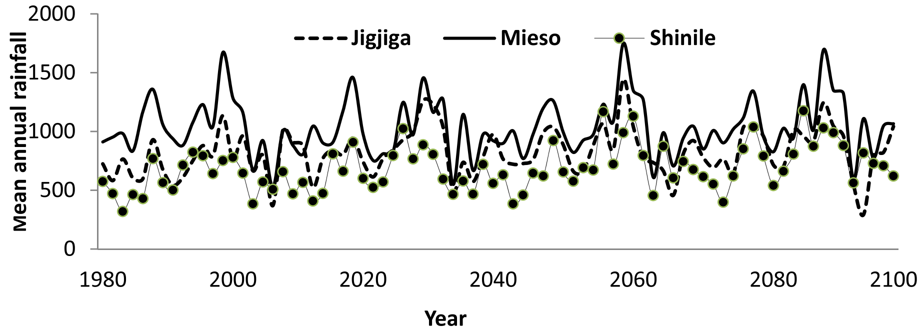

Fig. 4 Trends of current and future mean annual rainfall for Mieso, Jigjiga, and Shinile districts for the period 1984–2100

generate future rainfall trend (Sarr 2012), differences in topography, temperature, altitude, vegetation cover, atmospheric interaction, and land use management. The variability of future rainfall might be a great problem for altering the rangeland WRSI similar to what is happening today. Accordingly, the annual and seasonal predicted rainfall variability and increasing temperature which increase the rate of evapo-transpiration may limit the future rangeland WRSI values in the eastern part of Ethiopia.

When the amount of water that is required to replenish water lost through ET deviate below normal, the rangeland WRSI will decline. As a result, the vegetation cover, the size of rangeland, and net removal of CO_2 from the atmosphere might be reduced (Wise et al. 2009). A higher carbon stock was stored in the soils than in the aboveground vegetation (Bikila et al. 2016), indicating the importance of vegetation cover in preventing the release of carbon dioxide that could have great influence on climate variability and change. Therefore, any below normal rangeland WRSI distribution to rangeland ecosystem will have a significant implication in decreasing net carbon dioxide capture and vegetation degradation that will eventually interfere with the reduction in feed supply to livestock. Moreover, increasing temperature is thought to increase ET, which reduces water availability to rangelands. Ayalew et al. (2012) concluded that a slight increase in average surface temperature increased the likelihood of extreme weather. Similar findings were observed in this paper. According to IPCC (2007) report, an increasing surface temperature by about 0.2–0.3 °C over the last 25 years result in reduction of rainfall and a lot of plant species from the earth. Hence, mean annual rainfall variability and increasing temperatures will have impacts on the quality and quantity of pastures (Thornton et al. 2009) also reduce the grazing capacities of most rangelands (Shine and Dunford 2016), which is a critical constraints on livestock performance in the arid and semiarid ecosystems.

Conclusions

Our study indicated that rainfall trend and variability directly reflected the pattern of rangeland WRSI in eastern Ethiopia. Moreover, the future rainfall trend analysis indicated that there would be rainfall variability in the years 2020–2049, 2040–2069, and 2070–2099, and this rainfall variability is expected to limit the future rangeland water index in our study areas. Based on our study, it can be concluded that the historical rainfall variability data was important determinant of rangeland WRSI values and can be used as a reference point for decision-making tools beforehand to reduce the impact of rainfall variability on livelihoods of pastoral communities. Therefore, we suggested using our findings as an early warning planning to minimize potential livestock feed insecurity, and the severity of drought condition. Accordingly, conservation of rangelands, use of appropriate grazing management, capacity building on rangeland management systems, and enhancing rangeland productivity through enclosure management should be practiced to reduce atmospheric CO_2 and sustain rangeland productivity under the changing climate in the eastern part of Ethiopia.

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Authors' contributions

HA initiated the idea, collected the data, analyzed the data, interpreted the results, and drafted the manuscript. ZKT, AT, and DK initiated the idea and critically revised the manuscript. All authors revised the manuscript, read, and approved the final version.

Competing interests

The authors declare that they have no competing interests.

Publisher's Note

Author details

[1]School of Animal and Range Sciences, College of Agriculture and Environmental Sciences, PO Box 138, Dire Dawa, Ethiopia. [2]School of Animal and Range Sciences, Hawassa University, PO Box 222, Hawassa, Ethiopia. [3]Famine Early Warning Systems Network, PO Box 1090, Addis Ababa, Ethiopia. [4]School of Animal and Range Sciences, College of Agriculture and Environmental Sciences, Haramaya University, PO Box 1632, Dire Dawa, Ethiopia.

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