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Temporal climate conditions and spatial drought patterns across rangelands in pastoral areas of West Guji and Borana zones, Southern Ethiopia

Tesfaye Dejene[1*], Gemedo Dalle[2], Teshale Woldeamanuel[1] and Muluken Mekuyie[1]

Abstract

Climate change and its variability adversely impact pastoral livelihoods, and understanding climate variability and its change is important to deduce policy implications for pastoral communities. Accordingly, the aim of this study was to investigate the temporal climate conditions and spatial patterns of drought across the rangelands in pastoral areas of West Guji and Borana Zones, Southern Ethiopia. Temporal climate conditions were performed at the rangeland level, and spatial drought patterns (distributions) were estimated across the sample *Kebeles* (*Kebele* is the smallest administrative unit in Ethiopia which works in the Duda rangeland) and *Reeras* (*Reeras* refer to the smallest customary administrative unit in the Borana Zonal administration) structures. Station-satellite temperature and rainfall data (38 years from 1981 to 2018) were obtained from the Ethiopian Meteorological Agency. For data analysis, the Mann–Kendall trend test was employed to test rainfall, temperature and drought patterns, while Sen's slope was used to test their magnitude of change, and coefficient of variation was employed to estimate rainfall and temperature variability. Standardized precipitation index was used to estimate drought event, while inverse distance-weighted method was used to estimate spatial drought patterns. The study reveals very high temporal rainfall variability with notable disparities in the rangelands mainly attributed to climate change. Besides, the study area exhibits high spatial variability of drought signifying agro-ecological characteristics in the rangelands. In the Duda and Gomole rangelands, annual rainfall increased non-significantly by 0.01 and 0.03 mm per annum, respectively. The annual minimum temperature in both Duda and Gomole increased significantly by 0.008 and 0.007 ℃ per year, respectively, albeit the annual maximum temperature in the rangelands decreased non-significantly by 0.02 and 0.009 ℃ per annum. Both rangelands experienced high annual rainfall variability, increasing annual minimum temperature, drought frequency and severity. Therefore, the outcome of the study is believed to be vital for identifying drought hotspot areas in the rangelands and devising strategies that help to reduce drought impacts on pastoral communities in Southern Ethiopia.

Keywords Borana, Climate change, Climate variability, Drought, Guji, Rangeland

Introduction

Climate change is a global problem with irreversible impacts on the environment, human livelihoods and food security (Mengistu et al. 2020; Habte et al. 2021). The current pace of climate change is unprecedented in human history (IPCC 2021). Current climate change features are climate variability and increased frequency, severity and duration of extreme climate events (Mohammed et al.

*Correspondence:
Tesfaye Dejene
tesfayedejene2011@gmail.com
[1] Wondo Genet College of Forestry and Natural Resources, Hawassa University, PO. Box 128, Shashemene, Ethiopia
[2] Center for Environmental Science, Addis Ababa University, PO Box 1176, Addis Ababa, Ethiopia

2018; Ahmad and Afzal 2021). Mean global land and sea temperatures shows an increasing trend of 0.08 °C over the past century and 0.6 °C over the past 30 years (Hessebo et al. 2019; IPCC 2021). In Africa, surface temperature increased by more than 0.5 °C per year over the past 50 to 100 years, with minimum temperature increased faster than maximum temperature (Nicholson et al. 2013). However, there is no clear trend in precipitation worldwide (NOAA 2020). Positive trends in some regions are associated with an increased frequency of heavy rain, while negative trends in other regions are associated with drought (Habte et al. 2021). Moreover, rainfall in East Africa is characterized by a high degree of temporal and spatial variability attributed to a variety of topographical features (Seneviratne et al. 2012). Similarly, rainfall in Ethiopia has shown large variations in time and space, due to the complex topography in the northern parts of the country (Abegaz and Mekoya 2020).

Climate change was seen in Ethiopia as increasing variability, decreasing/or increasing magnitudes of rainfall and temperature change and the incidences of climate extremes (Zerga and Gebeyehu 2016; Kourouma et al. 2022). The temperatures in the semi-arid areas of Ethiopia increased to levels above the national average and the highland regions (Wassie and Fekadu 2014; Tolera and Senbeta 2020). In particular, the mean annual temperature in the Borana, Guji and South Omo pastoral areas in Southern Ethiopia increased by 0.40 °C per decade between 1950 and 2000 (Fenta 2017). Additionally, data from pastoral areas in Southern Ethiopia (mainly Borana) revealed decreased rainfall trends, which were the driver of pasture and water scarcities (Riché et al. 2009; Tache 2010; Wassie and Fekadu 2014; Birhanu et al. 2017). As a result, the pastoral communities' ability to adjust to and recuperate from the effects of the drought was obstructed (Birhanu et al. 2017). Moreover, the Guji, Borana and Gabra pastoral and agro-pastoral communities in Southern Ethiopia have suffered from repeated drought-induced water shortages and livestock die-offs, particularly the cattle loss (Urge and Mieso 2019; Tolera and Senbeta 2020). For instance, in the Guji Zone Liben district between 2007 and 2008, about 3000 cattle died due to drought-induced water and pasture scarcities (Mekuria et al. 2021). In addition, in the Burkitu basin, Southern Ethiopia, during the 2015/2016 drought, 498 cattle, 1103 goats, 72 sheep, 25 camels and 89 chickens died (Guye et al. 2022). This really requires research-based climate and drought management strategies for pastoral communities in Ethiopia (Fenta et al. 2019).

Of course, various studies have been conducted to assess the climate and drought variability in Southern Ethiopia, especially in the areas closest to the meteorological stations. However, some of these findings contradict each other. For example, Habte et al. (2021) reported that rainfall and temperature variation were highly variable associated with the increase in minimum and maximum temperature from 1983 to 2016 in the Ari and Konso regions of Southern Ethiopia, while Ayal et al. (2018) revealed that autumn and spring rainfall in the pastoral areas of Borana showed a high variation from 1985 to 2014, accompanied by a decrease in rainfall and an increase in minimum and maximum temperatures. Tolera and Senbeta (2020) showed the change in mean annual rainfall from 1980 to 2010 with a slight decreasing trend in Yabello Meteorological station in Southern Ethiopia. Furthermore, mean annual maximum and minimum temperatures increased with decreased annual rainfall in the Nyangatom agro-pastoral areas near Jinka and Turmi Meteorological stations in the Lower Omo Valley in Southern Ethiopia (Kebede et al. 2021). The differences among the results of previous studies are attributed to differences in the scopes of study areas in Southern Ethiopia. Most studies have been conducted on larger areas using a single Meteorological station's rainfall and temperature data (Cheung et al. 2008). Furthermore, there are limited studies on temporal climate conditions and spatial drought patterns across rangelands in pastoral areas of Southern Ethiopia, especially where meteorological stations are unavailable (Gemeda 2019; Tolera and Senbeta 2020; Kourouma et al. 2022). Accordingly, the present study aimed to investigate the temporal climate conditions and spatial drought patterns across rangelands in pastoral areas of West Guji and Borana Zones, Southern Ethiopia. The specific objectives are to (i) estimate the temporal variation of rainfall and temperature in the rangelands; (ii) analyse rainfall and temperature changes on the studied rangelands; and (iii) identify spatial drought patterns in the studied rangelands. In general, such a study across rangelands could be seen as an additional pathway for climate research in the arid and semi-arid regions where pastoral communities live. Overall, the results of this study can be incorporated into the formulation of climate policies and strategies in Ethiopia.

Study area

The study was carried out across the rangelands (Dheeda[1]) in West Guji and Borana Zones, Southern Ethiopia. West Guji zone is located between 5° 05′ N and 5° 74′ N, and 37° 8′ E and 38° 8′ E, while Borana zone is located between 3° 51′ N and 5° 32′ N, and 36° 6′ E and 39° 74′ E. The sample rangeland of West Guji zone-Duda rangeland is located between 5° 05′ N and 5° 29′ N and 37° 90′ E and 38° 50′ E. The sample

[1] Dheeda is a literary name for rangeland, in Guji and Borana pastoral areas.

rangeland of Borana zone-Gomole rangeland is located between 3° 97′ N and 5° 08′ N, and 37° 80′ E and 39° 90′ E (Fig. 1). The climate of West Guji zone rangelands is mostly semi-arid; however, the climate of Borana zonal rangelands is both arid and semi-arid. Furthermore, the rainfall pattern in Southern Ethiopia, particularly in the West Guji and Borana Zones, is bimodal. It includes (i) long rainy season or spring rainfall (Bokkeya Gannaa) incorporating rainfall from March, April and May and (ii) short rainy season or autumn rainfall (Bokkeya Hageyya) incorporating rainfall from September, October and November (Dadi 2013; Mekonnen et al. 2017; Dinku 2018; Mera 2018). However, the previously known bimodal rainfall pattern is changing, and variability is progressively increasing in Southern Ethiopia (Dejene 2020). Similarly, the rangelands in Southern Ethiopia are characterized by bimodal dry seasons: (i) a warm dry season (Bona Hageyya) comprising December, January and February and (2) a cool dry season (Bona Adooleesa) consisting June, July and August. The type of vegetation covers the study rangelands are tropical savannah, with varying proportions of open grasslands and perennial herbaceous and woody vegetation (Homann 2004; Dalle et al. 2006). The topography of the Guji and Borana rangelands is flat, with occasional volcanic cones and depressions (Abate 2016). The elevation of the West Guji zonal area ranges from 914 to 2740 m above sea level. Borana's zonal altitude ranges from 461 to 2483 m above sea level (Desta and Coppock 2004). The total land areas of West Guji zonal rangelands are 18,577 km^2, while the Borana zonal rangelands are 95,000 km^2 (Coppock 1994). A tarmac road runs north to south through both zonal rangeland areas, connecting the border town of Moyale with Ethiopian capital—Addis Ababa (Dalle et al. 2006).

Methods

Sampling procedures

The sample study areas were selected using both probabilistic and non-probabilistic sampling methods. First, the rangelands were carefully selected using number of grazing lands in the rangeland as a sampling criterion.

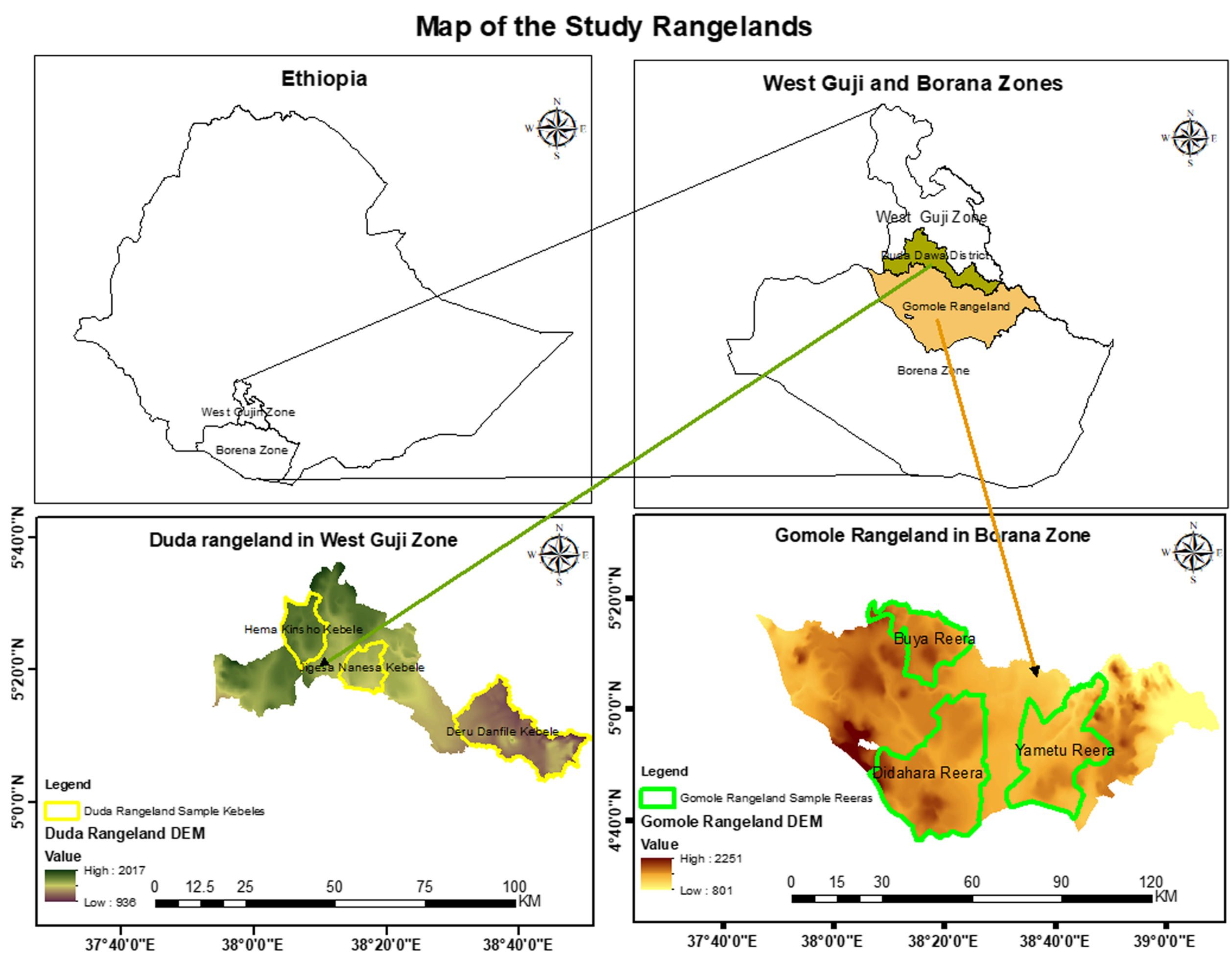

Fig. 1 Location map of the Duda and Gomole rangelands

Therefore, West Guji Zonal administration had four rangelands, namely Duda, Dawa, Cari and Galana. The highest grazing lands were found in Duda rangeland which was 17, relative to Dawa rangeland had 13, Cari rangeland had nine and Galana rangeland had 11 grazing lands, and so the Duda rangeland was selected for the current study. On the other hand, in the Borana Zonal administration, there were five rangelands, namely Gomole, Wayama, Malbe, Dire and Golbo. The highest numbers of grazing lands were found in Gomole rangeland which was 35, whereas the Dire rangeland had 30, Wayama rangeland had 17, Malbe rangeland had 21 and Golbo rangeland had 19 grazing lands. Therefore, Gomole rangeland was selected for the current study.

After rangeland selection, another parameter was considered, namely the rangeland tenure system for selecting the smallest administrative unit, which was subjected for the analysis of spatial drought patterns in the Duda and Gomole rangelands. Rangelands in the West Guji Zone, including the sampled Duda rangeland, belong to a state land tenure system called statutory land tenure system. *Kebele* is the smallest administrative unit of a state land tenure system in Ethiopia which works in the Duda rangeland. The Borana Zone Administrative rangelands, including the Gomole rangeland, were under customary land tenure system. A *Reera* is the smallest administrative unit on the outskirts of a customary land tenure system in the Borana Zonal administration. Therefore, the sample *Kebeles* from Duda rangeland and sample *Reeras* from Gomole rangeland were selected by stratified random method. Initially, a total of nine *Kebeles* in the Duda Rangeland and nine *Reeras* in the Gomole Rangeland were stratified as lowland (500 to 1500 m) and midland (1500 to 2300 m) agro-climatic regions. Then, three samples of *Kebeles* from Duda Rangeland (Deru Danfilé, Jigesa Nanesa and Hema Kinsho *Kebeles*) and three samples of *Reeras* from Gomole Rangeland (Didahara, Yametu and Buya *Reeras*) were randomly selected.

Rainfall and temperature data source

In this study, merged or combined station-satellite monthly minimum and maximum temperature and rainfall data were used. Merged station-satellite minimum and maximum temperature and rainfall and rainfall data were available for areas with homogeneous topographies (Dinku et al. 2013; Alemayehu et al. 2020) like the rangelands in Southern Ethiopia. In recent years, merged station-satellite rainfall and temperature datasets with varying spatial resolutions have been used in Ethiopia (Alemayehu and Bewket 2017). Therefore, for the current study, the data were downloaded with a spatial resolution or grid cell size of 0.0375 degrees or 4.16 × 4.16 km for both Duda and Gomole rangelands. The Ethiopian NMA conducted a data quality check, which included checking the study rangelands' coordinates and identifying suspicious rainfall values (Dinku et al. 2013). Finally, NMA has provided station-satellite monthly minimum and maximum temperature and rainfall data of 38 years (1981–2018) for both Duda and Gomole rangelands.

Method of data analysis

Various statistical methods were used for data analysis, such as coefficient of variation (CV), standardized precipitation index (SPI), Mann–Kendall trend test and Sen's slope estimator. For instance, CV was used to estimate the variability of rainfall and temperature over the last 38 years (1981–2018), in the study rangelands. It was calculated as the ratio of the standard deviation to the mean of rainfall and temperature between 1981 and 2018, multiplied by 100%. The higher the CV value, the larger the variability of rainfall /or temperature (Mohamed and El-Mahdy 2021). Accordingly, CV result was rated as low (CV < 20%), moderate (20% < CV < 30%) and high (CV > 30%) variability of rainfall and temperature (Eshetu et al. 2018; Mohamed and El-Mahdy 2021).

SPI was used to estimate drought incidence in the rangelands. It is the most commonly used method for estimating inter-annual and seasonal variations of drought severity (Mckee et al. 1993). SPI can be calculated for 1, 3, 6, 9, 12, 24 and 48 months timescales in general. As a result, SPI 3 months and SPI 12 months were used in this study to estimate seasonal and annual drought patterns (Mekonen et al. 2020). Drought begins when the SPI value falls below zero and ends when it rises above zero (Mckee et al. 1993; Abbas and Kousar 2021; Mekuyie and Mulu 2021). In this study, the SPI values suggested by Mckee et al. (1993) for drought severity classification was used. Accordingly, SPI values greater than 0 denote no drought, SPI values from 0 to −0.99 denote mild drought, SPI values from −1 to −1.49 denote moderate drought, SPI values from −1.5 to −1.99 denote severe drought and SPI values of −2 denote extreme drought. SPI is represented mathematically by Eq. 1:

$$\mathrm{SPI} = \frac{x\mathrm{i} - \bar{x}}{\alpha} \tag{1}$$

where xi is the monthly rainfall, (x) is the mean and α is the standard deviation of the specified periods' monthly rainfall.

Furthermore, SPI values were also used to calculate drought frequency, magnitude, intensity and severity. Drought frequency is about the time interval between drought events with threshold values of SPI ≤ −1. Drought magnitude (Dm) is the sum of all negative SPI values for all months, seasons or years during the drought period (Mckee et al. 1993) (Eq. 2). Drought duration (Dd) is the time between when a drought begins and when it ends, expressed in months, seasons or years, and is most likely calculated when the SPI value is equal to minus one (SPI = −1). Drought intensity (Di) is estimated as a ratio of drought magnitude and drought duration (Eq. 3). Drought severity (S) is the cumulative SPI values during the specified drought duration (Yisehak et al. 2021).

$$\mathrm{Dm} = -\sum_{i=1}^{n}\mathrm{SPI} \tag{2}$$

$$\mathrm{Di} = \frac{\mathrm{Dm}}{\mathrm{Dd}} \tag{3}$$

where Dm is the magnitude of drought, n is the number of seasons/year with a drought event at j time step, Dd is the duration of drought and Di is the intensity of drought.

The spatial patterns of drought severity in terms of annual and seasonal time steps were estimated using the inverse distance weight (IDW) interpolation method in arc GIS version 14. IDW is works based on a theory developed by a Tobler (1970) "everything is related to everything else, but near things are more related than distant things"; hence, points which are close to an output pixel will obtain large weights and that points which are farther away from an output pixel will obtain small weights (Hengl 2009). Furthermore, the IDW is a simple and effective tool to estimate spatial patterns of drought on flat land escapes like the studied rangelands (Birara et al. 2018; Yisehak et al. 2021).

Mann–Kendall trend test was used to estimate the trend of seasonal and annual rainfall, temperature and drought trends, whereas Sen's slope estimator was used to determine magnitude of change in rainfall, temperature and drought (Ayal et al. 2018; Eshetu et al. 2018; Mohammed et al. 2018). Equations 4, 5 and 6 show the Mann–Kendall trend test and Sen's slope estimator mathematically:

$$S = \sum_{i-1}^{N-1}\frac{\sum_{j=i-1}^{N}\mathrm{sgn}(xj - xi)}{\sigma} \tag{4}$$

$$\sigma = \sqrt{N(N-1)(2N+5) - \sum_{i=1}^{n}\mathrm{ti}\,(i-1)\,(2\mathrm{i}+5)/18} \tag{5}$$

where $\boldsymbol{S}$ is the Mann-Kendal trend test statistic; xi and xj are the sequential data values of the time series on either the season/annual time scales, where I and j ($j > I$ and N is the time series length (Eshetu et al. 2018). Sign $(xj - xi) = 1$ if $xj - xi > 0$; sgn $(xj - xi) = 0$ if $x = 0$; and sign $(xj - xi) = -1$ if $xj - xi = 0$. As a result, if the p-values are greater than the significance level, there is a statistically significant trend; thus, the larger the value of trend, the stronger the trend, and vice versa. Sen's slope estimator, on the other hand, was used to test the trend's slope. Sen's slope estimator is mathematically denoted as Eq. 6.

$$\mathrm{Senslope} = \mathrm{Median}\frac{(xi - xj)}{i - j}, j < i \tag{6}$$

where $\boldsymbol{xi}$ and xj are the variable's changing values at time steps i and j, respectively. A value near zero indicates that there is no slope of change. A negative slope value indicates the strength of a negative trend, whereas a positive slope value indicates the strength of a positive trend. Data analysis were performed using statistical packages such as Microsoft Excel 2010, Excel STAT 2020, MAKESENS Microsoft Excel add, IBM SPSS version 23, Drinc version 1.7 and arc GIS version 10.4.

Results

Temporal climate condition

The study results show the temporal climate conditions in Duda and Gomole rangelands in terms of climate variability and change over the past 38 years (1981–2018). Accordingly, Table 1 shows temporal variations of rainfall which was reported as monthly, seasonal and annual rainfall. The highest (147 mm) and lowest (14 mm) monthly rainfalls in Duda rangeland were recorded in April and January, respectively. Similarly, the highest (134 mm) and lowest (11 mm) monthly rainfalls have occurred in Gomole rangeland in April and January, respectively. Over the last 38 years, monthly rainfall in both the Duda and Gomole rangelands has been highly variable (CV ≥ 30%). The highest monthly rainfall variability was recorded in Duda rangeland in December of the warm dry season and in Gomole rangeland in February of the warm dry season (Table 1).

The results of seasonal rainfall recorded in the Duda and Gomole rangelands from 1981 to 2018 are presented in Table 1. As a result, the average spring rainfall in the Duda rangeland was 333 mm, accounting for 48% of the annual rainfall in the rangeland, whereas the average spring rainfall in the Gomole rangeland was 281 mm per season, accounting for 47% of the rangeland's average annual rainfall. The average autumn rainfall in the Duda rangeland was 217 mm per season, accounting for 31% of the rangeland's annual rainfall, whereas the autumn rainfall in the Gomole rangeland was 196 mm, accounting for 34% of the rangeland's annual rainfall. Furthermore, the average annual rainfall in the Duda and Gomole rangelands was 689 mm and 580 mm per year, respectively. To summarize, seasonal and annual rainfall in both the Duda and Gomole rangelands has been highly variable (CV ≥ 30%) over the past 38 years (1981–2018) (Table 1). In general, the seasonal and annual rainfall variability in Gomole rangeland was found to be greater than that

Table 1 Mean monthly, seasonal and annual rainfall in the study rangelands, *Kebeles* and *Reeras*

Variables	Duda rangeland		Gomole rangeland		Deru Danfile *Kebele*		Jigesa Nanesa *Kebele*		Hema Kinsho *Kebele*		Buya *Reera*		Yametu *Reera*		Didahara *Reera*	
	Mean (mm)	CV (%)	Mean (mm)	CV (%)	Mean (mm)	CV (%)	Mean (mm)	CV (%)	Mean (mm)	CV (%)	Mean (mm)	CV (%)	Mean (mm)	CV (%)	Mean (mm)	CV (%)
Jan	**14**	**114**	**11**	**115**	12	**115**	14	**149**	14	**128**	12	**123**	11	**139**	11	**112**
Feb	**22**	**118**	**17**	**124**	19	**122**	23	**172**	25	**126**	21	**135**	18	**147**	18	**115**
Mar	65	70	58	74	67	74	53	78	55	83	51	75	67	89	46	73
Apr	147	41	134	41	149	43	157	47	136	42	136	44	155	50	103	45
May	121	49	89	50	110	48	119	53	109	62	103	53	83	54	73	54
Jun	35	60	22	63	30	60	33	74	29	74	26	66	24	78	21	67
Jul	26	46	17	50	28	55	21	57	19	64	17	49	23	67	13	49
Aug	34	71	21	75	36	78	27	85	24	78	24	77	24	87	17	81
Sep	58	44	42	49	57	48	42	64	44	56	41	52	43	63	36	54
Oct	109	45	98	48	110	48	96	58	88	53	85	50	105	57	74	48
Nov	51	94	55	103	48	97	61	107	53	97	49	101	72	115	47	113
Dec	**17**	**125**	**15**	**122**	16	**129**	17	**130**	15	**119**	17	**131**	14	**124**	16	**126**
Spring	**333**	**58**	**281**	**60**	327	**51**	329	**54**	300	**57**	290	**53**	305	**60**	222	**54**
Autumn	**217**	**67**	**196**	**77**	215	**59**	200	**74**	185	**66**	176	**65**	219	**77**	157	**69**
Annual	**698**	**59**	**580**	**62**	684	**60**	662	**71**	609	**67**	583	**65**	637	**73**	474	**66**

Table 2 Mean monthly, seasonal and annual maximum and minimum temperature in the rangelands, *Kebeles* and *Reeras* (1981–2018)

Study sites	Variables	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Spring	Autumn	Annual
Duda rangeland	Mean Tmax (°C)	**28.5**	**29**	**28.8**	**27.2**	**26.3**	**25.8**	**25.8**	**26.1**	**27**	**26.8**	**27.3**	**28.1**	**27.4**	**27**	**27.2**
	CV (%)	**3.6**	**3.6**	**5.1**	**4**	**4.8**	**4**	**3.9**	**3.4**	**3.6**	**4.3**	**4.2**	**3.5**	**6**	**4.1**	**5.7**
	Mean Tmin (°C)	**13.5**	**14**	**14.2**	**14**	**14.1**	**13.8**	**13.4**	**13.4**	**13.5**	**13.7**	**13.1**	**12.9**	**14.1**	**13.4**	**13.6**
	CV (%)	**7.5**	**5.8**	**5.6**	**4**	**4.4**	**4.4**	**5.7**	**5.6**	**4.1**	**5.3**	**5.2**	**5.9**	**4.7**	**4.7**	**6**
Deru Danfile *Kebele*	Mean Tmax (°C)	29.2	29.4	29.5	27.9	27.2	27	27.2	27.7	28.4	28	28.1	28.9	28.2	28.2	28.2
	CV (%)	3.5	3.2	5	3.6	4.5	3.6	3.8	3.8	3.7	4.5	4.2	3.1	5.5	4.2	4.9
	Mean Tmin (°C)	13.9	14.1	14.4	14.2	14.3	14.1	13.8	13.7	13.9	13.9	13.3	13.1	14.3	13.7	13.9
	CV (%)	13.1	10.8	10.3	6.8	8.1	8.5	10.7	10.5	7.5	9	7.9	10.2	8.5	8.4	9.9
Jigesa Nanesa *Kebele*	Mean Tmax (°C)	31.3	31.8	30.9	29.8	28.6	27.5	27.6	27.4	29	29	29.8	30.7	29.8	29.3	29.4
	CV (%)	4.3	4.6	5.8	5.2	6.2	5.2	5.6	4	4.3	5.3	5.1	4.7	6.5	5	7
	Mean Tmin (°C)	15.9	16.8	16.6	16.2	16.6	16.2	15.9	15.9	15.8	15.8	14.5	15	16.5	15.4	15.9
	CV (%)	6.2	5	4.2	4.1	3.6	2.7	3.1	3	3	3.7	5	5.8	4.2	5.7	5.8
Hema Kinsho *Kebele*	Mean Tmax (°C)	28.4	29	28.5	27.1	25.9	25.1	24.9	25	26.1	26	26.7	27.7	27.2	26.3	26.7
	CV (%)	5.5	6.1	6.9	5.3	6.3	6.1	6.8	5.7	4.9	5.5	5.1	5.5	7.3	5.3	7.7
	Mean Tmin (°C)	14	14.7	14.9	14.6	14.7	14.1	13.8	13.8	13.9	14.2	13.5	13.5	14.7	13.9	14.2
	CV (%)	**6.4**	**6.3**	**7.2**	**6.5**	**5.8**	**4.9**	**5.2**	**4.8**	**4.9**	**5.7**	**5.5**	**7.5**	**6.5**	**5.7**	**6.7**
Gomole rangeland	Mean Tmax (°C)	**30.1**	**30.6**	**30**	**28.1**	**27.5**	**27.5**	**27.7**	**27.9**	**28.7**	**28.2**	**28.8**	**29.5**	**28.5**	**28.6**	**28.7**
	CV (%)	**2.9**	**3.1**	**5**	**3.8**	**3.8**	**3.5**	**3**	**2.6**	**2.8**	**4.1**	**3.9**	**2.4**	**5.7**	**5.7**	**5**
	Mean Tmin (°C)	**14.5**	**14.8**	**14.8**	**14.6**	**14.8**	**14.6**	**14.2**	**14.1**	**14.1**	**14.3**	**13.9**	**14.1**	**14.7**	**14.1**	**14.4**
	CV (%)	**3.8**	**3.3**	**4.2**	**3.5**	**2.9**	**2.8**	**3.3**	**3.6**	**3**	**2.8**	**2.9**	**3.5**	**3.6**	**3.6**	**4**
Buya *Reera*	Mean Tmax (°C)	29.8	30.4	29.6	28.2	27.1	26.5	26.7	26.6	27.7	27.6	28.5	29.2	28.3	27.9	28.2
	CV (%)	3.9	4.1	5.8	4.8	5.6	4.8	4.9	3.7	4.2	5.2	4.9	4	6.5	5	6.5
	Mean Tmin (°C)	14.5	15.2	15.2	14.9	15.2	14.7	14.4	14.3	14.3	14.5	13.6	13.8	15.1	14.1	14.6
	CV (%)	5.8	4.3	4.5	4.1	3.7	2.9	3.1	3.4	3.1	4	4.7	4.9	4.2	4.7	5.2
Yametu *Reera*	Mean Tmax (°C)	29.6	30.1	29.5	27.8	27.3	27.5	27.9	28	28.8	27.9	28.5	29.1	28.2	28.4	28.5
	CV (%)	2.6	2.8	5	3.9	3.7	3.3	2.9	2.6	2.8	4.4	4.1	2.4	5.4	4	4.6
	Mean Tmin (°C)	14.4	14.8	14.9	14.8	14.9	14.6	14.2	14.1	14.2	14.3	13.8	13.9	14.9	14.1	14.4
	CV (%)	5.2	4.5	4.7	3	2.9	3.7	4.3	4.6	3.6	3.1	2.8	3.8	3.6	3.6	4.7
Didahara *Reera*	Mean Tmax (°C)	29.6	30.3	29.1	27.2	26.5	26.6	27.2	26.8	27.5	27.1	28.4	28.8	27.6	27.7	27.9
	CV (%)	3.6	3.6	5.4	4.5	4.5	4.1	3.4	3.2	3.3	4.8	4	2.5	6.3	4.5	5.9
	Mean Tmin (°C)	14.1	14.5	14.5	14.6	14.6	14.2	13.8	13.7	13.7	13.9	13.6	13.6	14.6	13.7	14.1
	CV (%)	4.8	4.1	5	5.1	3.7	3	3.3	3.8	3.4	2.6	2.8	3.2	4.6	3.1	4.7

Tmax maximum temperature, *Tmin* minimum temperature

in Duda rangeland. The variability of rainfall in both rangelands was directly proportional to the amount of rainfall received by the rangelands. For example, areas that received less rainfall were more likely to experience higher rainfall variability, whereas areas that received more rainfall were more likely to experience lower rainfall variability in both rangelands (Table 1).

The average seasonal and annual minimum and maximum temperatures recorded in the Duda and Gomole rangelands over the last 38 years are shown in Table 2. As a result, the average spring and autumn temperatures in Duda rangeland were 20.8 and 20.2 °C respectively, while the average spring and autumn temperatures in Gomole rangeland were 21.6 and 21.3 °C. The average spring maximum and minimum temperatures in Duda rangeland were 27.4 and 14.7 °C respectively, while the average spring maximum and minimum temperatures in Gomole rangeland were 28.5 and 14.7 °C. The average autumn maximum and minimum temperatures in Duda rangeland were 27 and 13.4 °C respectively, while in Gomole rangeland average autumn maximum and minimum temperatures were 28.6 and 14.1 °C. Furthermore, the average annual temperatures in the Duda and Gomole rangelands ranged between 21.4 and 21.3 °C. The seasonal and annual minimum and maximum temperatures were found to be less variable in both the Duda and Gomole rangelands (Table 2). In both the Duda and Gomole rangelands, there were no significant differences

Table 3 Trend of seasonal and annual rainfall in the study rangelands (1981–2018)

Study areas	Mann–Kendall trend (*Z* test)			Sen's slope (*Q*)		
	Spring	Autumn	Annual	Spring	Autumn	Annual
Duda rangeland	**−0.25**[a]	**1.13**	**0.68**	**−0.24**	**0.62**	**0.01**
Gomole rangeland	**0.2**	**2.61**	**2.19**	**0.08**	**0.99**	**0.03**
Deru Danfile *Kebele*	0.48[b]	2.19	2.34	0.31	1.08	5.73
Jigesa Nanesa *Kebele*	−0.55	1.06	0.25	−0.39	0.62	0.97
Hema Kinsho *Kebele*	−0.75	0.25	−0.73	−0.40	0.22	−2.35
Buya *Reera*	−0.3	0.98	0.28[b]	−0.23	0.43	0.76
Yametu *Reera*	0.58	3.34	3.49	0.32	1.77	8.91
Didahara *Reera*	0.13	2.84	2.16	0.06	0.99	3.14

[a] Significant at 0.01 level, [b] significant at 0.05 level

in monthly, seasonal and annual maximum and minimum temperature variation (Table 2).

Table 3 shows the seasonal and annual rainfall trends, and spring rainfall in Duda rangeland showed a statistically significant decreasing trend ($P<0.01$), whereas spring rainfall in Gomole rangeland showed a non-significant increasing trend. Autumn and annual rainfall in both the Duda and Gomole rangelands increased significantly. Furthermore, Sen's slope results revealed that spring rainfall in Duda rangeland decreased by 0.24 mm per season, while it increased by 0.08 mm per season in Gomole rangeland. Similarly, autumn rainfall in the Duda and Gomole rangelands did not significantly increase. Annual rainfall has increased by 0.01 mm and 0.03 mm per year in Duda and Gomole rangelands respectively (Table 3). In general, the annual rainfall magnitude of change in the Gomole rangeland was found to be greater than the change in the Duda rangeland. Spring rainfall in the Duda rangeland has decreased, while it has increased in the Gomole rangeland (Table 3). As a result, decreasing spring rainfall may pose a challenge for pastoral and agro-pastoral livestock and crop production in the study rangelands.

The Mann–Kendall trend test and Sen's slope results in Table 4 show that the seasonal and annual maximum and minimum trend and magnitude of change in both the Duda and Gomole rangelands. Thus, the spring maximum temperature in both Duda and Gomole rangelands showed a significantly decreasing trend ($P<0.05$) over the last 38 years (1981–2018), accompanied by a 0.03 °C magnitude decrease, whereas the spring minimum temperature showed a non-significantly increasing trend in Duda rangeland by 0.002 °C magnitude increase, and a non-significantly decreasing trend in Gomole rangelands with a 0.01 °C magnitude decrease. Furthermore, the autumn maximum temperature in both the Duda and Gomole rangelands decreased non-significantly, whereas the autumn minimum temperature increased significantly ($P<0.05$) by 0.013 and 0.014 °C, respectively. The annual mean minimum temperature in the Duda rangeland increased non-significantly, whereas it has increased significantly ($P<0.1$) in the Gomole rangeland (Table 4).

Spatial drought patterns

The results in Table 5 show temporal (seasonal and annual) drought variability characterized in terms of drought frequency, magnitude, intensity and severity in both Duda and Gomole rangelands over the course of 38 years (1981–2018). For illustration, Duda rangeland was smashed by 16 droughts during spring and autumn seasons, as well as eight annual droughts, whereas Gomole rangeland was shattered by 16 spring and autumn droughts, in addition to seven annual droughts. The magnitudes of the spring (−9.72), autumn (−8.55) and annual (−10.57) droughts in Duda rangeland were found to be greater than those of the Gomole rangeland spring (−9.27), autumn (−7.13) and annual (−8.60) droughts. Nonetheless, over the last 38 years (1981–2018), the annual drought severity (−2.81) in Gomole rangeland was greater than that in Duda rangeland (−2.45). The seasonal and annual drought intensity in Duda rangeland was found to be greater than that in Gomole rangeland (Table 5).

The temporal characteristics of seasonal and annual drought severity in the Duda rangeland are depicted in Fig. 2. Thus, during the spring season, Duda rangeland experienced six moderate droughts (in 1991, 1998, 1999, 2007, 2008 and 2015) and two severe droughts (in 1984 and 2017), while the rangeland experienced four moderate (1991, 1993, 1999 and 2003) and four severe (1998, 2015, 2016 and 2018) autumn droughts. Furthermore, over the past 38 years (1981–2018), the Duda rangeland experienced two moderate, six severe and one extreme annual drought (2015) events.

Table 4 Trend of seasonal and annual temperatures in the study rangelands (1981–2018)

Study areas	Mann–Kendall trend (*Z* test)									Sen's slope (*Q*)								
	Spring (MAM)			Autumn (SON)			Annual			Spring (MAM)			Autumn (SON)			Annual		
	Tmx	Tmn	Mean	Tmx	Tmn	Mean	Tmx	Tmn	Mean	Tmx	Tmn	Mean	Tmx	Tmn	Mean	Tmx	Tmn	Mean
Duda rangeland	**−2.3[c]**	**0.2**	**−1.8**	**−1.2**	**2.0[c]**	**−0.3**	**−2.0[c]**	**1.0**	**−1.2**	**−0.03**	**0.002**	**−0.02**	**−0.02**	**0.013**	**−0.003**	**−0.02**	**0.008**	**−0.008**
Gomole rangeland	**−2.0[c]**	**−1.3**	**−1.8**	**−1.1**	**4.1[b]**	**0.0**	**−0.8**	**1.8[d]**	**−0.5**	**−0.03**	**−0.01**	**−0.02**	**−0.02**	**0.015**	**0.000**	**−0.009**	**0.007**	**−0.003**
Deru Danfile *Kebele*	−2.8[b]	−1.8[d]	−2.5	−1.9[d]	1.7[d]	−1.4	1.91[d]	0.58	−1.3	−0.04	−0.01	−0.03	−0.02	0.009	−0.02	−0.02	0.004	−0.01
Jigesa Nanesa *Kebele*	−2.2[c]	1.3	−1.2	−0.7	3.1[b]	0.4	1.71[d]	1.94[d]	−0.8	−0.04	0.01	−0.01	−0.01	0.02	0.006	−0.025	0.013	−0.008
Hema Kinsho *Kebele*	−1.8[d]	2.7[b]	0.0[b]	−0.4	3.5[a]	1.2	−1.56	2.60[c]	0.03	−0.03	0.03	0.00	−0.01	0.04	0.01	−0.02	0.026	0.001
Buya *Reera*	−2.4[c]	0.5	−1.2	−0.7	3.2[b]	0.2	−1.43	2.11[c]	−1.0	−0.03	0.00	−0.02	−0.01	0.02	0.002	−0.03	0.011	−0.09
Yametu *Reera*	−2.3[c]	−0.7	−2.0	−1.4	3.4[b]	−0.1	1.84[d]	1.84[d]	−0.3	−0.03	0.00	−0.02	−0.02	0.02	−0.001	−0.01	0.012	−0.001
Didahara *Reera*	−2.1[c]	−1.1	−2.0	−1.2	3.1[b]	−0.2	0.93	1.63	−0.6	−0.03	-0.01	−0.02	−0.02	0.01	−0.002	−0.008	0.007	−0.003

[a] Significant at the 0.001 level; [b]significant at the 0.01 level; [c]significant at the 0.05 level; [d]significant at the 0.1 level

Table 5 Seasonal and annual droughts variability in the rangelands (1981–2018)

Timescale	Drought frequency	Drought magnitude	Drought intensity	Drought severity	Years of observation
	Duda rangeland				
Spring	**8**	**−9.72**	**−1.39**	**−1.84**	1984, 1991, 1998, 1999, 2007, 2008, 2015 and 2017
Autumn	**8**	**−8.55**	**−1.43**	**−1.84**	1991, 1993, 1998, 1999, 2003, 2015, 2016 and 2018
Annual	**8**	**−10.57**	**−1.76**	**−2.45**	1984, 1991, 1994, 1998, 1999, 2009, 2015 and 2016
	Gomole rangeland				
Spring	**8**	**−9.27**	**−1.32**	**−2.14**	1983, 1984, 1991, 1997, 2008, 2011, 2015 and 2017
Autumn	**8**	**−7.13**	**−1.19**	**−1.78**	1984, 1991, 1993, 1998, 2008, 2009, 2015 and 2016
Annual	**7**	**−8.60**	**−1.54**	**−2.81**	1983, 1984, 1987, 1992, 1997, 2015 and 2016

On the other hand, the temporal characteristics of seasonal and annual droughts in Gomole rangeland are depicted in Fig. 3. According to the findings, Gomole rangeland experienced five moderate (in 1983, 1991, 1997, 2011 and 2015), two severe (in 1984 and 2017) and one extreme (in 2008) spring droughts, while the rangeland experienced three moderate (in 1993, 2008 and 2009) and five severe (1984, 1991, 1998, 2015, 2018) autumn droughts. Furthermore, over the last 38 years, the Gomole rangeland has experienced two moderate, three severe and two extreme annual droughts (2015 and 2016).

Figure 4 depicts the spatial variation of seasonal and annual droughts in the Duda rangeland. As a result, spring moderate drought occurred in the western, central, southern and eastern corridors of the Duda rangeland, while severe spring drought occurred in the rangeland's north-western, south-western, southern, central and eastern corridors. Moderate annual drought occurred in the rangeland's southern, central, western and eastern regions, while severe and extreme annual drought occurred in the rangeland's northern, southern, western and south-western regions (Fig. 4).

On the other hand, the northern, central and southern regions of the Gomole rangeland experienced moderate spring drought, while the vast areas in the rangeland's western and eastern regions experienced severe spring drought. Extreme spring drought has occurred in the rangeland's north-central, central and southern regions. Furthermore, the Gomole rangeland in the south, southwest, central, east and north experienced moderate autumn drought. A severe autumn drought confounded the rangeland's north-west, central and eastern regions (Fig. 5).

Table 6 displays the spatial characteristics of drought trends in the Duda and Gomole rangelands. As a result, spring drought in Duda rangeland Deru Danfile *Kebele* was likely to be reduced, despite the fact that it was increased in Jigesa Nanesa and Hema Kinsho *Kebeles*. With the exception of Hema Kinsho *Kebele*, autumn and annual droughts increased in all rangeland *Kebeles*. In Gomole rangeland, however, spring drought episodes in Buya *Reera* have decreased over the last 38 years, whereas spring drought episodes in Yametu and Didahara *Reeras* have increased. Furthermore, both the autumn and annual droughts in Yametu and Didahara *Reeras* are likely to have been exacerbated. As a result, there has been a greater spatial variation in autumn and annual drought trends across *Kebeles* in Duda rangeland and *Reeras* in Gomole rangeland over the last 38 years (1981–2018).

Discussion

Temporal climate conditions

The present study revealed that the seasonal and annual rainfall in Duda and Gomole rangelands remained highly variable (CV ≥ 30%) over the past 38 years. According to reports, rainfall variations in Southern Ethiopia were mainly due to seasonal movement of the Intertropical Convergence Zone (ITCZ); heat flows from the lands of the Sahara and Arabia; the rise of subtropical highs over the Azores and Saint Helena Islands in the South Atlantic Ocean and the Mascarene Islands in the Southern Indian Ocean; moist flow across the south/south-west equator from the southern Indian Ocean; central tropics; tropical extreme easterly rays spill over Ethiopia; and Somali low-altitude jets (Suryabhagavan 2017; Mera 2018; Abegaz and Mekoya 2020; Alhamshry et al. 2020; Degefu et al. 2021). Consistent to the current study findings, Ayal et al. (2018) reported high rainfall variability of spring and autumn seasons in Borana Zone between 1985 and 2014. The study results were inconsistent with the results came from Konso district of southern Ethiopia (Araro et al. 2019). The discrepancy between annual rainfall variability in the studied rangelands and the Konso district mainly was due to the elevation difference between the two regions. In general, higher annual rainfall variability (CV ≥ 30%) likely to be associated with more frequent

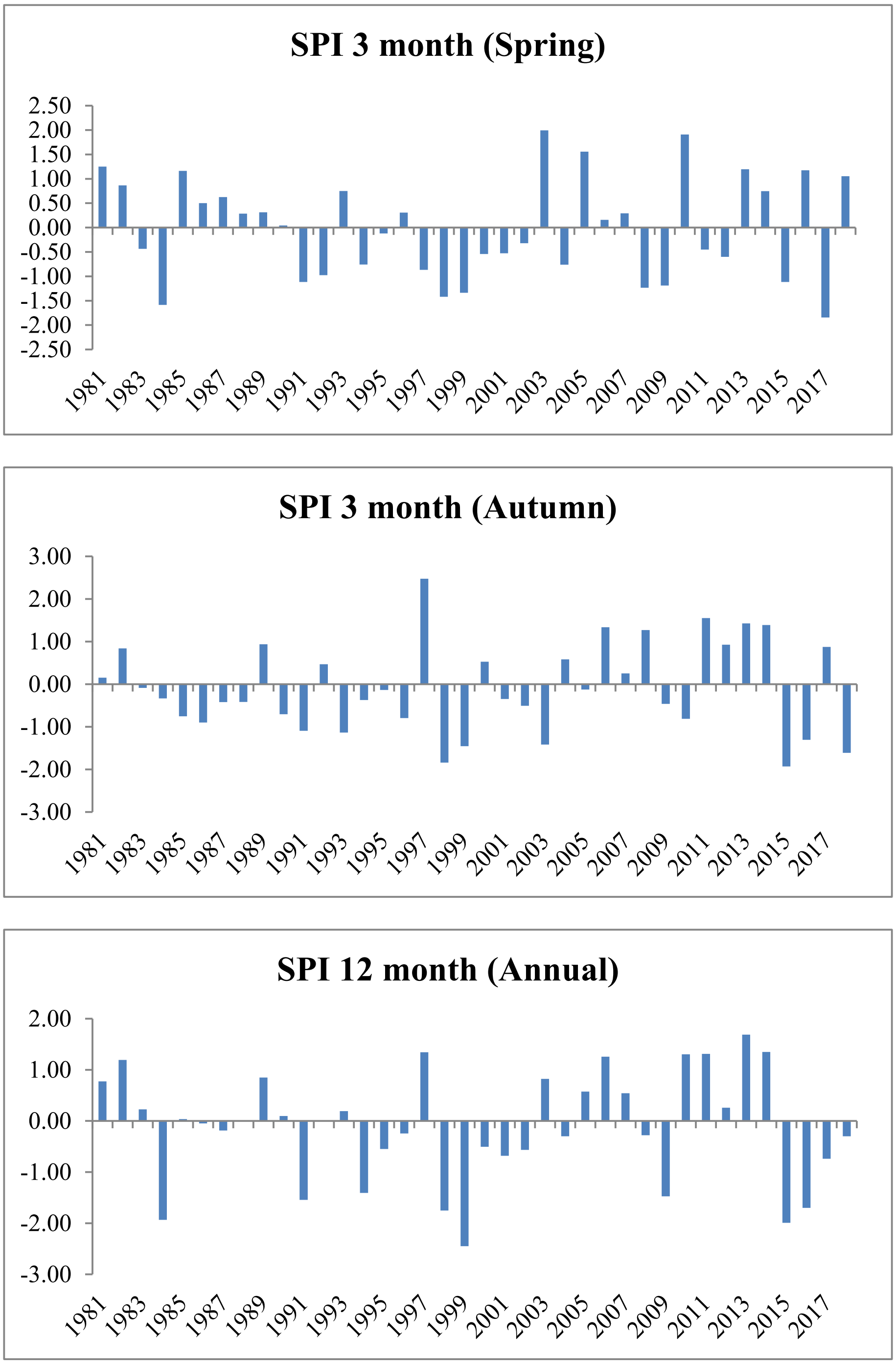

Fig. 2 Seasonal (SPI 3) and annual (SPI 12) droughts in the Duda rangeland

and severe drought occurrences (Mera 2018; Hessebo et al. 2019) and resulted in poor crops harvest or crops failure, as well as a scarcity of pasture and livestock feed problems in Southern Ethiopia's pastoral areas (Angassa and Oba 2008; Wako et al. 2017).

The seasonal and annual minimum and maximum temperatures in the Duda and Gomole rangelands were less variable throughout the study periods. In contrast to the current study results, the results from Deder District of Oromia Regional State in Eastern Ethiopia showed

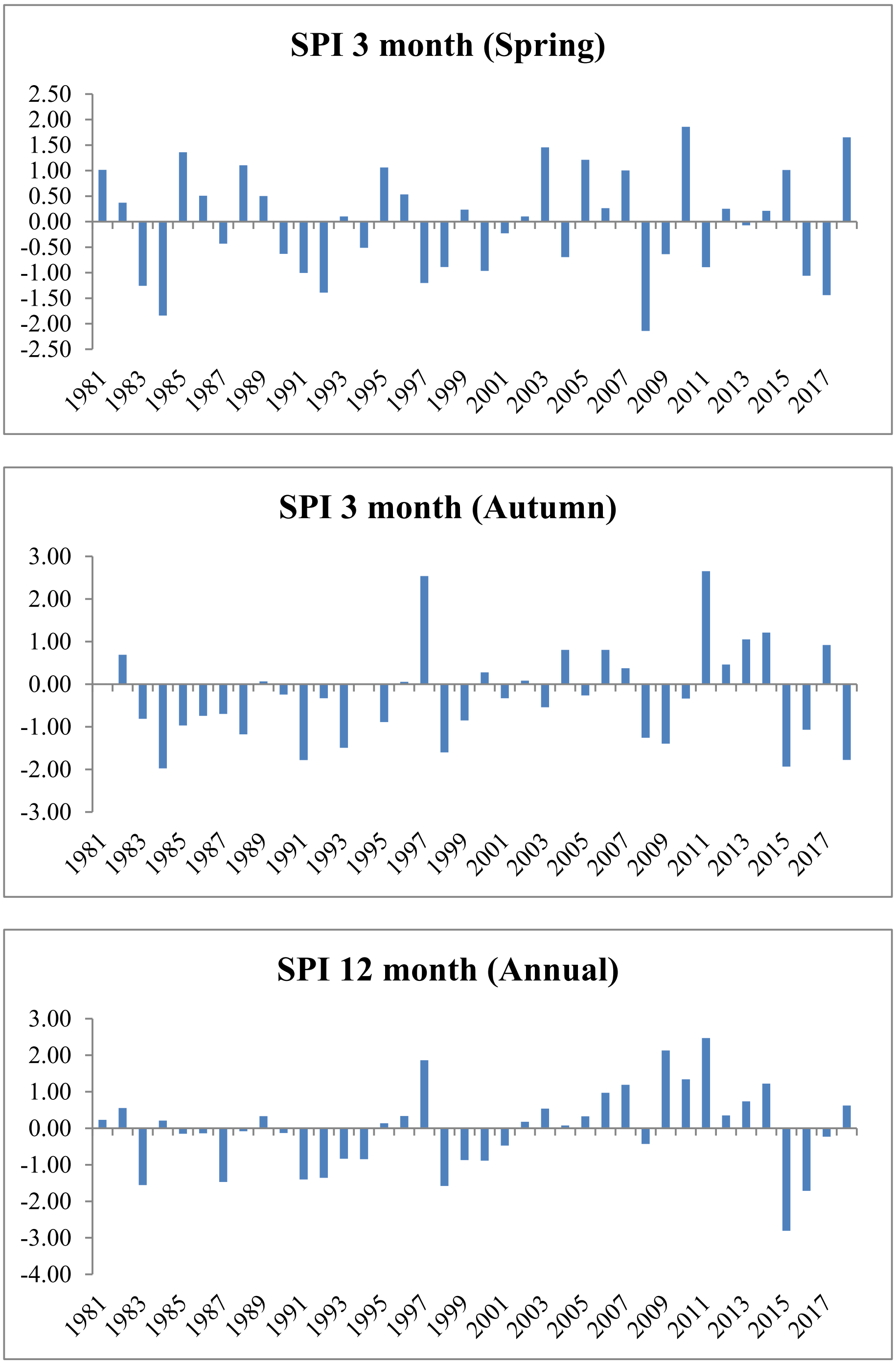

Fig. 3 Seasonal (SPI 3) and annual (SPI 12) droughts in the Gomole rangeland

significantly higher variability of annual minimum and maximum temperatures between 1988 and 2018 (Mengistu et al. 2020). This was primarily due to the difference in study year between the current study and the study conducted in Deder district. Furthermore, the results of a study in Southern and South-eastern Ethiopia showed significant differences from the study results in terms of annual maximum and minimum temperature variation (Abebe 2017). In fact, Abebe (2017) used only one weather station (Nagele weather station) to study climate of the entire Southern Ethiopia between 1955 and 2015. As a result, representing the climatic conditions of large

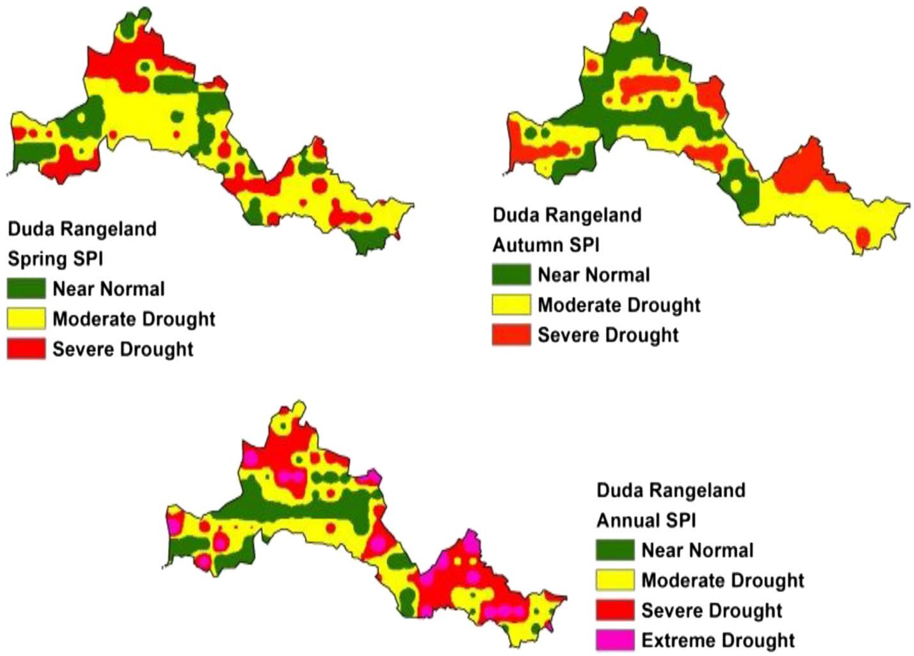

Fig. 4 Spatial pattern of seasonal and annual drought in the Duda rangeland

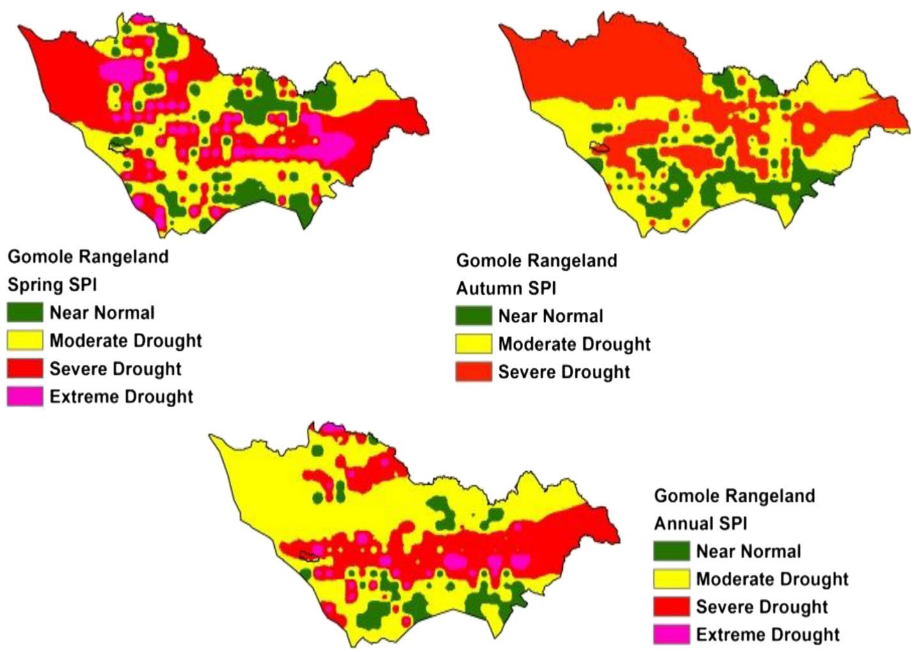

Fig. 5 Spatial pattern of seasonal and annual drought in the Gomole rangeland

pastoral areas in Southern Ethiopia using data from the Nagele weather station proved difficult. Furthermore, an altitudinal difference between the studied rangelands and the Nagele meteorological station causes a disparity in the climatic conditions of both areas.

In terms of seasonal and annual rainfall change, spring rainfall in Duda rangeland decreased by 0.24 mm per season from 1981 to 2018, while spring rainfall increased by 0.08 mm per season in Gomole rangeland. Spatially, spring rainfall in the Duda Rangeland at Deru Danfile

Table 6 Drought trends in the study rangelands (1981–2018)

Study sites	Mann–Kendall trend (*Z* test)			Sen's slope (Q)		
	Spring	Autumn	Annual	Spring	Autumn	Annual
Duda rangeland	**−0.28**	**1.13[c]**	**0.70**	**−0.01**	**0.02**	**0.01**
Gomole rangeland	**0.28[b]**	**2.59[c]**	**2.14[b]**	**0.01**	**0.03**	**0.03**
Deru Danfile *Kebele*	0.48	2.19[c]	2.34[c]	0.009	0.037	0.038
Jigesa Nanesa *Kebele*	−0.55	1.06	0.25	−0.011	0.022	0.005
Hema Kinsho *Kebele*	−0.75	0.25	−0.73	−0.012	0.007	−0.015
Buya *Reera*	−0.30	0.98	0.28	−0.007	0.014	0.006
Yametu *Reera*	0.58	3.34[a]	3.49[a]	0.010	0.049	0.054
Didahara *Reera*	0.13	2.84[b]	2.16[c]	0.003	0.042	0.030

[a] Significant at 0.001, [b]significant at 0.01 level, [c]significant at 0.05 level

Kebele increased significantly, while rainfall decreased at Jigesa Nanesa and Hema Kinsho *Kebeles*. In addition, spring rainfall decreased in the Gomole rangeland, although it increased slightly in Yametu and Didahara *Reeras*. Consistent to the study results, spring rainfall in Deder district decreased by 8.2 mm per season from 1988 to 2018 (Mengistu et al. 2020). Furthermore, spring rainfall in the southern, south-western and south-eastern regions of Ethiopia decreased between 1975 and 2010 (Mekuria et al. 2021). Spring rainfall in Ethiopia's Oromia Regional State decreased by 3.0 mm per season between 1983 and 2017 (Mekuyie and Mulu 2021) and similarly, spring rainfall in the Borana pastoral area has decreased by 31.28 mm per decade over the past 28 years (1987–2014) (Ayal et al. 2018). However, autumn rainfall in Duda rangeland has increased by 0.62 mm per season over the last 38 years, while similar autumn rainfall in Gomole rangeland has increased by 0.99 mm per season. Abara et al. (2020) discovered a negligible increase in autumn rainfall in South-eastern Ethiopia, which is consistent with the study results. Autumn rainfall, on the other hand, has increased in the Segen pastoral areas of South Omo pastoral areas of South-western Ethiopia, ranging between 0.21 and 5.87 mm per season (with an average of 2.5 mm per season) (Habte et al. 2021). Furthermore, annual rainfall decreased between 1980 and 2017 at the meteorological stations of Arbamich, Yabello, Moyale, Nagele and Kabridar in Southern Ethiopia, with the exception of Gode in South-eastern Ethiopia (Abara et al. 2020). As likely as the current study, annual rainfall in the Aghini pastoral areas of the Afar Regional State in Ethiopia's north-eastern region decreased significantly between 1963 and 1997 (Hassen 2008).

Disagreeing with the results of the present study, the annual minimum and maximum temperature increased in the pastoral district of Fentale, Oromia regional state in Ethiopia between 1983 and 2017 (Mekuyie and Mulu 2021). Another study conducted in the Negele town in Southern Ethiopia found that the town's average annual temperature has increased by 0.3 °C over the past 50 years (Wassie and Fekadu 2014). In addition, the study results from Arsi Nagele district in South-central Ethiopia in terms of mean maximum and minimum temperatures showed an increasing trend with magnitudes of 0.028 and 0.047 °C, respectively between 1983 and 2014 (Mekonnen et al. 2017). The average annual temperature in all parts of South-western Ethiopia has increased by 0.021 °C per year (Habte et al. 2021). Furthermore, the increasing mean annual temperature for the North Shewa areas was by rate of 0.03 °C per year reported, particularly in the Kolla agro-ecological regions (Shekuru et al. 2020). In general, the current study findings were consistent with those from the Alwero Watershed in North Western Ethiopia, which revealed a non-significantly decreasing trend in mean annual temperature (Alemayehu et al. 2020).

Spatial drought patterns

The trend of drought episodes in spring and autumn was found to be higher in Duda rangeland than in Gomole rangeland. Drought episodes in Ethiopia were caused by the warming effects of the Pacific, Indian and Atlantic oceans, according to studies (Funk et al. 2012; Viste et al. 2012). As a result, in terms of annual drought frequency, the Duda rangeland appears to have experienced two annual droughts between 1984 and 1991, and six between 1992 and 2016. However, Gomole's rangeland experienced two annual droughts between 1983 and 1984, as well as five annual droughts between 1985 and 2016. Furthermore, research findings from the northern escarpments of the Ethiopian rift valley (the Raya Valley and its foothills) show that annual droughts were more common between 1989 and 2016 than autumn drought episodes (Nasir et al. 2021).

Drought severity remained higher in Gomole rangeland than in Duda rangeland. As previously mentioned, worsening droughts are increasing livestock mortality in pastoral areas of Southern Ethiopia, particularly in Borana pastoral area (Wario 2011; Funk et al. 2012). For example, the spring drought of 1984 was caused by an increase in sea surface temperatures (SST) in the equatorial Atlantic Ocean (Dadi 2013). Most recently, extreme drought in Ethiopian rangelands in 2015/16 was exacerbated by the El Niño event in the Pacific Ocean, supercharged by global climate change (Oxfam 2016), and herds are highest in pastoral areas in Southern Ethiopia, mainly in Guji, Borana, Gabra and some parts of the Somali Regional State that have been affected (Mekuria et al. 2021). According to Mera (2018), the areas most affected by drought in Ethiopia are largely inhabited by pastoral communities who depend mainly on livestock for their livelihood. The severity of drought in pastoral areas in Ethiopia's Oromia region is exacerbated by climate change, affecting the delicate balance underlying pastoral production systems, depleting water resources and encroaching unpalatable bushes on rangelands (Wako et al. 2017). In general, droughts are getting worse at times, posing a major threat to pastoral communities in Southern Ethiopia. Severe droughts severely affected livestock and crops and exacerbated food insecurity (Kassaye et al. 2021), and hence, destitute and displaced pastoralist has emerged in Southern Ethiopia (Wako et al. 2017).

Scientific and policy contributions of the study

The finding of the present study is believed to make scientific contributions in the following areas: (i) the temporal climate conditions and spatial distribution of droughts estimated across the rangelands could be taken as an additional climate research pathway in pastoral land escapes and (ii) the study has shown that there was no direct association between "rainfall and drought trends" in the studied rangelands as anticipated, because the analysis reveals increasing trends of annual and seasonal rainfall and drought over the years in both rangelands, except trends of spring drought in Duda rangeland. Accordingly, the question appeared to our mind is that "how drought happens with increasing rainfall trends in both rangelands?" This calls for further scientific study on the association between local climate and causes of drought.

In addition, the finding of the study is believed to be taken as an important input for pastoral policy development by the government and other stakeholders wishing to take action to reduce climate and drought impacts in Ethiopia. Accordingly, according to the study results, the areas which received higher rainfall variability and severe and extreme droughts need similar policy interventions than the areas with moderate drought in the rangelands. Because, climate-related shocks, such as drought, and increasing minimum temperature can reduce water and pasture availability in pastoral rangelands of Ethiopia. Moreover, the observed impacts of rainfall variability and drought severity on pastoral communities in the present study would be more pronounced in the near future (Kebede et al. 2021). Therefore, a range of measures are expected to be implemented now and the projection of the likelihood of future drought occurrences should be conducted for the studied rangelands, to reduce the existential as well as the imminent threats of drought to pastoralist livelihoods (Eriksen and Marin 2011; Gebremichael et al. 2022).

Conclusions

This study reveals that seasonal and annual rainfall exhibits high temporal variability in both Duda and Gomole rangelands during the study period (1981–2018). However, the seasonal, annual minimum and maximum temperatures were found to be less variable over the years in both rangelands. Moreover, the trends of seasonal and annual drought vary spatially among *Kebeles* of Duda rangeland and *Reeras* of Gomole rangeland. Similarly, in Duda rangeland, severe and extreme annual droughts occurred in northern, southern, western and south-western regions in the rangeland implying spatial disparity. Besides, in Gomole rangeland, severe and extreme droughts occurred in north-western, central, south-eastern and south-western parts of the rangeland. In general, drought frequency, magnitude and intensity were higher in Duda rangeland, while seasonal and annual drought severity was higher in Gomole rangeland. Furthermore, the local rainfall condition in the studied rangelands has no significant effect on the annual and seasonal drought patterns in the rangelands. This study failed to project future temporal climate conditions and spatial drought patterns across rangelands of Southern Ethiopia. Therefore, further studies are needed to estimate temporal climate conditions and spatial drought patterns in rangelands in pastoral areas of Southern Ethiopia. Overall, the results of this study are important for a better understanding of drought hotspots in the rangelands, which could be used as a baseline for designing drought management strategies to reduce impacts on pastoral communities in Southern Ethiopia.

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Authors' contributions

The first author (TD) analysed the data and drafted the manuscript paper, which is part of the first author's PhD dissertation in Climate Change and Bioenergy Development at Wondo Genet College of Forestry and Natural Resources Hawassa University, Ethiopia. The second author (GD) and the third authors (TW and MM) fully participated in manuscript development and they edited and commented on the manuscript paper. All authors read and agreed upon the manuscript paper.

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Availability of data and materials

The rainfall and temperature data used in this study are available from the corresponding author upon request. However, permission is required from Ethiopian Meteorological Agency.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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