Exploring smallholder farmers' perceptions of climate change and its adaptation options in the Dire Dawa administration zone, Eastern Ethiopia

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Abstract

Purpose – This study aims to explore the smallholder farmers' perceptions of climate change and its adaptation options (changing crop variety; improved crop and livestock; soil and water conservation [SWC]; and irrigation practices) and drought indices in the Dire Dawa Administration Zone, Eastern Ethiopia.

Design/methodology/approach – A cross-sectional household survey was used. A structured interview schedule for respondent households for key informants and focus group discussions were used. This study used both descriptive statistics and an econometric model. The model was used to compute the determinants of climate adaptation options in the study area. Drought characterization was carried out by DrinC software.

Findings – The results revealed households adapted to selected adaptation options. The model results confirmed that education level, farm size, tropical livestock units (TLUs) and access to agricultural extension services have positive and significant impacts on changing crop variety by 0.0014%, 0.045%, 0.032% and 0.035%, respectively. The likelihood of farmers' decisions to use adaptation strategies (family size, TLU, agricultural extension service and distance from the market) has positive and significant impacts on SWC. The reconnaissance drought index (RDI6) of ONDJFM and AMJJAS showed extreme and severe drought index values of −2.88 and −1.96, respectively.

Originality/value – This study used a locally adopted climate change adaptation intervention for smallholder farmers, revealing the importance of drought characterization indices both seasonally and annually.

Keywords Adaptation option, Climate change and variability, Drought indices, Smallholder farmer, Eastern Ethiopia

Paper type Research paper

Declarations:

Author contribution statement: Girma Asefa Bogale contributed to the study by conceptualizing and designing the survey methodology, curating the data, analyzing and interpreting the data and writing the original paper.

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1. Introduction

Climate change is one of the most talked and it is widely recognized as one of the most significant environmental issues that mankind badly faces today (Al Mamun and Al Pavel, 2014). Climate changes revealed that changes in temperature and rainfall, resulting in increases in frequency and intensity of floods, cyclones and drought events, have affected the livelihoods, cultures and health of people on earth (Al Mamun and Al Pavel, 2014; Barnett, 2003; IPCC, 2007b; Ogata and Sen, 2003). In developing countries, adapting the agricultural sector to climate change is critical to sustaining the livelihoods of impoverished communities (Niang *et al.*, 2014). Smallholder farmers in Ethiopia typically have limited access to land and rely on traditional farming methods, which hinders their ability to adopt more advanced agricultural practices and reduces their vulnerability (USAID (United States Agency International, for D, 2015). Smallholder farmers may face reduced agricultural productivity as they struggle to cope with climate change impacts and lack access to complementary services such as extension, credit and marketing (Asrat and Simane, 2017).

Adaptation to climate change is one of the approaches considered likely to reduce the impacts of long-term changes in climate variables (Al Mamun and Al Pavel, 2014). Furthermore, adaptation is a process by which strategies to moderate and cope with the consequences of climate change impact variability can be enhanced, developed and implemented (Al Mamun and Al Pavel, 2014; UNDP, 2004). According to the findings of Codjoe *et al.* (2014), Elum *et al.* (2017), Mekonnen *et al.* (2018) and Simelton *et al.* (2011), smallholder farmers' adaptation practices are closely linked to their perceptions of changing rainfall and temperature patterns. Smallholder farmers may only adopt adaptation strategies if they are aware of climate change and its potential impacts. Incorporating farmers' perceptions and local knowledge (Darabant *et al.*, 2020; Niles and Mueller, 2016) can improve the adoption and durability of adaptation strategies by enabling the development of location-specific and contextually relevant solutions. Recent decades have witnessed an increase in the frequency of drought and irregular precipitation, a trend that is projected to continue and worsen under future climate change (Deressa *et al.*, 2009; Viste *et al.*, 2013). Ethiopia's agriculture is already highly susceptible to climate change and the resulting crop failures (Alemu and Mengistu, 2019).

To reduce the negative effects of climate variability and change on livelihoods and ecosystems, vulnerable farmers need to adopt appropriate technologies (Sissoko *et al.*, 2011). Climate change has significantly disrupted hydrological cycles, precipitation patterns and temperature trends in many parts of the world (IPCC, 2007a). Smallholder farmers in eastern Ethiopia are particularly at risk from the impacts of climate change because the Dire Dawa district heavily relies on climate-sensitive smallholder agriculture. Smallholder farmers are heavily influenced by their perceptions of the weather when adopting appropriate agricultural adaptation strategies (Patt *et al.*, 2005; Patt and Gwata, 2002). Climate change has a negative impact on food security by reducing productivity and livelihood options (Chichongue *et al.*, 2015). Adaptation is widely recognized as a crucial approach to addressing the threat of climate change and improving the resilience of resource-constrained farm households in dryland agricultural systems, which are often highly vulnerable to climate change (Antwi-Agyei and Nyantakyi-Frimpong, 2021; Sonko *et al.*, 2020; Tambo and Abdoulaye, 2013).

Drought-prone communities in arid and semi-arid regions face increasing risks to their livelihoods and survival because of increasing frequency, severity and water availability (Ulrichs *et al.*, 2019). Drought is a natural hazard with direct and significant impacts on agriculture. Droughts directly impact agriculture, causing severe food security issues and climate disasters (Lesk *et al.*, 2016; Peña-Gallardo *et al.*, 2019; Sheffield *et al.*, 2014; Zhao and Running, 2011). In the context of the Dire Dawa area, climate variability, including drought and flooding, poses significant problems. Dire Dawa is situated within the Great Rift Valley lands of Ethiopia, which makes it susceptible to these climatic challenges. There exists a lack of harmony between smallholder farmers' perceptions and climate change adaptation options. Unfortunately, there is a lack of available and well-studied research on recent data regarding these drought-prone areas. Therefore, the overall objective of this study was to explore smallholder farmers' perceptions of climate change and its adaptation options in the Dire Dawa administration zone, eastern Ethiopia.

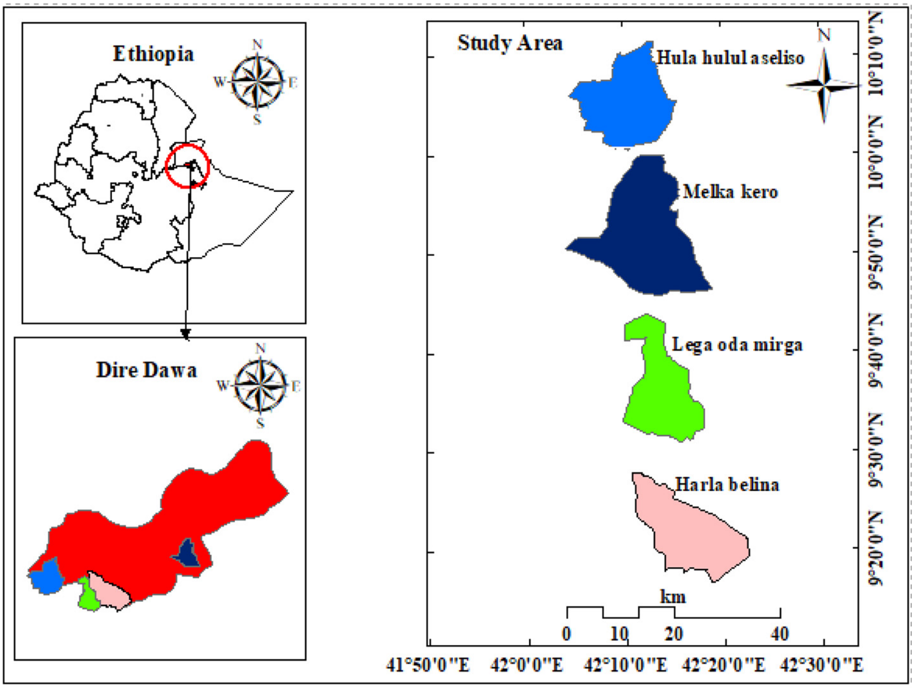
2. Materials and methods

2.1 Description of the study area

The research was conducted in the Dire Dawa administration zone, located in eastern Ethiopia with an elevation of 1,183 m.a.s.l. (Figure 1). The area is situated 527 km east of Addis Ababa and has a high population density, unpredictable rainfall, frequent droughts, crop failure, significant land degradation and chronic food insecurity (Tesfaye and Seifu, 2016). Smallholder farmers in the zone are skilled in growing vegetables and root crops, intercropping and using irrigation. Sorghum and maize are the main crops grown under rainfed conditions, while khat, potatoes and vegetables such as lettuce, carrot, onion, tomato and cabbage are crops grown under irrigated conditions (Setegn *et al.*, 2011).

2.2 Methods of data collection

2.2.1 Historical climate data. For this study, historical daily precipitation (mm) and maximum and minimum temperatures (oC) from 1993 to 2022 for the Dire Dawa district



Source: Author's own creation

Figure 1.
Map of the study area

were provided by the Ethiopian National Meteorological Institute. The lowest and highest temperatures recorded in Dire Dawa were 18.92°C and 32.5°C, respectively, with an average annual rainfall of 277.1 mm. The area experiences a bimodal rainfall pattern. The month of August experiences a high monthly rainfall distribution event, while December experiences a low event (Figure 2).

2.2.2 Data sources and types. The study used a cross-sectional survey, both primary and secondary data from various sources. Primary data was collected by administering questionnaires and key informant interviews to obtain information on climate change, variability, and adaptation options over the past 1993–2022 years. Secondary information on climate change and adaptation strategies was obtained from published and unpublished sources. Both open-ended and closed-ended questionnaires were used to minimize risk and ensure a comprehensive analysis of the data. The quantitative data questionnaire was written in English and translated into the local language, "Afan Oromo," to aid respondents in understanding the questions and facilitate data collection during the household survey. Focus group discussions were used as a qualitative data collection method, bringing together a group of community members (typically 8–10 individuals) to engage in discussions regarding climate change and its adaptation options for smallholder farmers in the study area. Key informant interviews were conducted to gather qualitative data, using the insights gained from the household survey. The interviews focused on agricultural extension services, district agricultural office personnel and experienced farmers who possess extensive expertise in farming practices and land management.

2.2.3 Determination of sampling technique and sample size. First, four kebeles out of the 32 in Gorgora district, Dire Dawa administration zone, were chosen for the study to account for the variations in the impacts of adaptation and variability among smallholder farmers. Second, the sample size of 146 household heads in each of the four kebeles was chosen proportionally for interviews using the Kothari (2004) formula (Table 1). This is a practical sampling method that is cost-effective and easier to use, even in areas with large populations.

$$n = \frac{NpqZ^2}{e^{2(N-1)} + pqZ^2} = \frac{4989 * 0.5 * 0.5 * 1.96^2}{0.08^2(4989 - 1) + 0.5 * 0.5 * 1.96^2} = 146$$

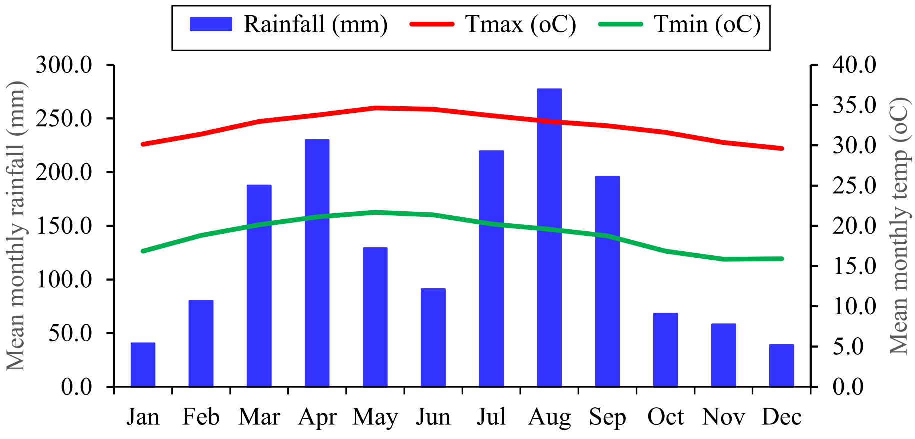


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Figure 2.
Climate information for the Dire Dawa area from 1993 to 2022

where n = the desirable calculated sample size, $Z(\alpha/2) = 1.96$ (95% confidence level for two sides), n = sample size to be computed, e^2 = acceptable error or level of precision desired setting at (8%), p = proportion of population and barriers (50%), $q(1 - p)$ = probability of failure.

$$ni = \frac{Ni + n}{N}$$

where ni is the sample size proportion to be determined, Ni is the population proportion in the stratum in kebele, n is the sample size and N is the total number of populations.

2.4 Data analysis

The study used both descriptive statistics and econometric approaches in the quantitative analysis. Simple descriptive statistics measures, such as frequency, percentage and mean, were applied to tables, bar graphs and line graphs with Origin Pro version 2021 software. The research used Stata version 13, R_studio version 4.2.3 and DrinC version 1.7 statistical software to assess data on the respondents' demographic variables and drought indices.

2.4.1 Climate variability and trend analysis. In this study, the coefficient of variation (CV%) is calculated to evaluate the variability of rainfall and temperature in the study area, as computed:

$$CV = \frac{\delta}{\mu} \times 100$$

where σ is the standard deviation and μ is the mean; CV is the coefficient of variation, S is the standard deviation and $\bar{x}$ is the mean for rainfall. When CV < 20% is less variable data, CV from 20% to 30% is moderate variable and CV > 30% is defined as highly variable. Areas with CV > 30% are said to be vulnerable to drought (Hare, 1983).

Mann–Kendall trend of non-parameters tests were performed using the Xlstat 2018 software, which tests for a trend in a time series without specifying whether the trend is linear or non-linear (Yue *et al.*, 2002). This test is widely used to analyze the monotonically increasing or decreasing trends in climate change research (Deng *et al.*, 2018; Sarricolea *et al.*, 2019; Zhang *et al.*, 2015; Zhang *et al.*, 2009). The ZM test statistic "S" is calculated based on Kendall (1975b) and Mann (1945) using the following formula:

$$s = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgs(xj - xi)$$

The application of the trend test is done to the time series X_1 that is ranked from i = 1, 2...n−1 and X_j that is ranked from j = i + 1, 2...n. Each of the data points Xi is taken as a reference point, which is compared with the rest of the data points X_j so that:

Table 1. Household sample size determination

Name of *kebele*	Total household size	Sample size
Haralla belina	1,240	36
Laga oda mirga	999	29
Melka kero	1,157	34
Hula hulul aseliso	1,593	47
Total	4,989	146

Source: Author's own creation and own computation (2023)

$$\text{sgs}\,(\text{xj} - \text{xi}) = \left\{ \begin{array}{l} +1\,\text{if}\,(\text{xj} - \text{xi}) > 0 \\ 0\,\text{if}\,(\text{xj} - \text{xi}) = 0 \\ -1\,\text{if}\,(\text{xj} - \text{xi}) < 0 \end{array} \right\}$$

where x_i and x_j are the annual values in years i and j (j > i), respectively. It has been interpreted that when the number of observations is more than 10 ($n \geq 10$), the statistic "S" is approximately normally distributed with the mean and E(S) becoming 0 (Kendall, 1975a). In this regard, the variance statistic is given:

$$\text{Var}(\text{S}) = \frac{\text{n}(\text{n}-1)(2\text{n}+5) - \sum_{t=1}^{m} f1(\text{t}_1 - 1)(2\text{t}_1 + 5)}{18}$$

where n is the number of observations and t_i are the ties of the sample time series. The test statistics for Z_c are as follows:

$$Z = \left\{ \begin{array}{l} \frac{\text{s}-1}{\delta}\,\text{if}\,\text{s} > 0 \\ 0\,\text{if}\,\text{s} = 0 \\ \frac{\text{s}+1}{\delta}\,\text{if}\,\text{s} < \text{mml} : 0 \end{array} \right\}$$

where Z_c follows a normal distribution, a positive Z_c and a negative Z_c depict an upward and downward trend for the period, respectively. If Zc appears greater than $Z\alpha/2$, where α depicts the significance level, then the trend is considered as significant. Sen's slope is applied to calculate the magnitude of the trend for temperature and rainfall data and is considered better to detect the linear relationship as it is not affected by outliers in the data (Ray *et al.*, 2021).

2.4.2 Drought index characterization. The computations of the standardized precipitation index (SPI), agriculture standardized index (ASPI) and reconnaissance drought index (RDI) were done in the drought index calculator (DrinC). To do this, the gamma distribution (Thom, 1966) was fitted to historical monthly rainfall using RStudio software. The probability density function of the gamma distribution is presented as follows:

$$g(x) = \frac{1}{\beta^{\alpha_{\tau}(\alpha)}} x^{\alpha-1} e^{\frac{-x}{\beta}} for\, x > 0$$

where g(x) is a probability density function, α is a shape parameter ($\alpha > 0$), β is a scale parameter ($\beta > 0$), ($x > 0$) and

$$\tau(\alpha) \int_{0}^{\alpha} \text{y}^{\text{a}-1} e^{-1} \text{dy}$$

$\tau(\alpha)$ is the gamma function.

The parameters α and β are estimated using the following formulas:

$$\alpha = \frac{1}{4A}\left[1 + \sqrt{1 + \frac{4A}{3}}\right]$$

$$\beta = \frac{x}{\alpha}$$

where $A = \ln \bar{x} - \frac{\sum \ln \bar{x}}{n}$, n is the number of precipitation observations and $\bar{x}$ is the mean precipitation over the time scale of interest.

When the probability density function is integrated with respect to x using the estimates of α and β, a cumulative probability G(x) of an observed amount of rainfall in a given month and time scale is obtained as follows:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\tau(\bar{\alpha})}\int_0^x x^{\bar{\alpha}} e^{\frac{\bar{x}}{\beta}} dx$$

$$G(X) = \int_0^x g(x)dx = e^{2x}$$

Substituting t for $\frac{\bar{x}}{\beta}$ in the equation above gives:

$$G(x) = \frac{1}{\tau(\bar{\alpha})}\int_0^x t^{\bar{\alpha}-1} e^{-1} dt$$

which is an incomplete gamma function. However, the gamma distribution function is undefined for x = 0 and $_q = P(x = 0) > 0$, where $P(x = 0)$ is the probability of zero precipitation. Hence, Usman *et al.* (2014) suggested that the actual probability of non-exceedance H(x) should be calculated as:

$$H(x) = q + (1 - q)G(x)$$

where H(x) is the actual probability of non-exceedance and q the probability of x = 0. If m is the number of zeros in a sample of size n, then q is estimated as:

$$q = \frac{m}{n}$$

The initial formulation of RDI_{st} (Tsakiris and Vangelis, 2005) used the assumption that $\delta\alpha k$ values follow the Gamma distribution. So, RDI_{st} was calculated as:

$$RDI_{st}^{(i)}{}_{(k)} = \frac{y_k^{(i)} - \bar{y}k}{\partial yk}$$

in which, yk is the $\ln(\alpha k(i)$, $\bar{y}k$ was the arithmetic mean of yk and $\bar{\partial} yk$ is the standard deviation.

The cumulative distribution function is transformed into a normal distribution for the estimation of DI using the following approximation (Abramowitz *et al.*, 1965):

$$DI = -\left(t - \frac{c_o + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right), for\, 0 < Hx \leq 0.5$$

In which $t = \sqrt{\ln\left(\frac{1}{1-H(x)^2}\right)}$, for $0 < \text{H}(\text{x}) \leq 0.5$

Where $c_o = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189269$, $d_3 = 0.001308$.

Because of the probabilistic nature of index calculation, the length of the input data time series plays an important role. The SPI, aSPI and RDI values can be negative or positive, with negative values indicating drought and positive values indicating wet periods. To determine the intensity of wet or dry conditions in the study area of the Dire Dawa district, a Table of SPI, aSPI and RDI magnitude (Table 2) was used.

2.4.3 Econometric analysis. The multinomial logit (MNL) model was used to examine the factors impacting smallholder farmers' use of adaptation techniques to mitigate the consequences of climate change in the research area, as well as their perceptions of temperature and precipitation. Studies on adaptation to climate change often use MNL (Alexandersson, 1986; Matewos, 2019). The question is how changes in the elements of X effect, keeping other factors constant, and the response probabilities, $P(Y = j\,|x), j = 0, 1, 2 \ldots J$. $P(Y = |x)$ are known after determining the probabilities for $j = 2 \ldots J$. Because the probabilities must sum to unity, let x be a 1*k vector with the first element unity. Thus, the probability that a household i with a characteristic X chooses an adaptation option j is specified as follows (Greene, 2009).

$$P(Y_i = j|\chi) = \frac{\exp(\chi\beta_j)}{[1 + \sum_{j=1}^{n} \exp\ (\chi\beta_j)]}$$

where P is the probability, j denotes adaptation options, x denotes the explanatory variables and $\beta_j = kx1$ is the coefficients, j = 1, 2, . . ., M. The dependent variables included in the model in this study were adaptation strategies by smallholder farmers in the study area, which were obtained from the survey data collected. These variables included changing crop variety, improved crops and livestock, soil-water conservation and supplementary irrigation practices. The independent (explanatory) variables were obtained from the survey data (Table 3).

The marginal effects or marginal probabilities are functions of the probability itself and measure the expected change in probability of a particular choice being made with respect to a unit change in an independent variable from the mean as computed.

Table 2. Standardized precipitation index (SPI) values

SPI values	Interpretation
≥ 2.0	Extremely wet
1.5 to 1.99	Severely wet
1.0 to 1.49	Moderately wet
0.99 to −0.99	Near normal
−1.0 to −1.49	Moderately dry
−1.5 to −1.99	Severely dry
≤ -2.0	Extremely dry

Source: Author's own creation

Variable	Description	Value	Expected sign	Sources
age	Age of household head	Continuous variable	+	Deressa *et al.* (2009); Tesso *et al.* (2012)
sex	Gender of household head	Dummy variable	–	–
edu	Level of education in the household head	Continuous variable	+	Deressa *et al.* (2009); Legesse *et al.* (2013)
fsize	Family size	Continuous variable	+	–
frmsize	Farm size	Continuous variable		Taddesse (2011) Tessema *et al.* (2013)
TLU	Livestock holding	Continuous variable	+	Deressa *et al.* (2009); Taddesse (2011)
credit	Access to credit service	Dummy variable		Deressa *et al.* (2009); Tesso *et al.* (2012)
agriexs	Access to agricultural extension service	Dummy variable	+	Falco *et al.* (2011)
onfarm	On farm income	Continuous variable	–	Barrett and Reardon (2001)
offarm	Off farm income	Continuous variable	–	Chalchisa and Sani (2016)
dmkt	Distance from the market	Dummy variable	–	Maddison (2006)
climinfor	Access to climate information	Continuous variable	+	Baethgen and Meinke (2003); Jones (2003); Maddison (2006)

Source: Author's own creation

Table 3. Summary variables affect farmers' choice of adaptation option to climate change

$$\frac{\partial \rho_j}{\partial x_k} = \rho_j \left(\beta_{jk} \sum_{j=1}^{J} \rho_j \beta_{jk} \right)$$

3. Results and discussions

3.1 Background of the respondents

Table 4 shows the demographic characteristics of the respondents, including gender, age and education. The majority of the survey respondents were women (71.23%), indicating that most household heads in the farming community are female. Among the respondents, 21.92% were aged between 15 and 30, 45.21% were between 31 and 45, 29.85% were between 46 and 65 and 2.74% were 65 years of age or older. In terms of education, 27.40% of respondents had completed grades 1–8, 13.70% had completed grades 9–12 and 4.11% and 8.22% had college degrees, respectively. Additionally, the majority of respondents (42.47%) were classified as having illiterate skills.

3.2 Variability and trends of rainfall and temperature characteristics

Table 5 presents the annual, seasonal and monthly precipitation in the study area. The average annual precipitation in the study area from 1993 to 2022 was 920.84 mm, with a medium CV of 27.6% and a standard deviation (SD) of 254.21 mm. The study indicates that the belg (FMAM) rainfall variability was higher than the kiremt (JJAS) season (Table 5). According to previous research (Abebe, 2006), the southwest and central highlands of the

Table 4. Demographic character of the respondents in the study area

Variables	Response	Frequency	%
Sex	Male household head	42	28.77
	Female	104	71.23
	Total	146	100.0
Age (years)	15–30	32	21.92
	31–45	66	45.21
	46–65	44	30.14
	≥65	4	2.74
	Total	146	100.00
Education level	Literate (Grades 1–8)	40	27.40
	Grades 9–12	20	13.70
	Diploma	6	4.11
	Degree	12	8.22
	Illiterate	62	42.47
	Total	146	100

Source: Own survey data (2023)

Table 5. Descriptive statistics of monthly, *belg*, *kiremt* and annual rainfall in Dire Dawa district (1993–2022)

Variables	Min.	Max.	Mean	SD	CV%	MK	S.slope
Jan	0	31.36	11.06	12.44	112.5	−1.28	0.000
Febr	0	76	15.95	21.14	132.5	−2.13**	−1.256
March	2	151.47	47.87	42.23	88.2	−0.84	−0.862
April	21.72	208.2	113.45	54.70	48.2	−1.94	−2.496**
May	17.5	115.54	104.26	48.65	46.7	0.64	0.357
Jun	18.12	147.21	58.92	32.72	55.5	0.75	0.214
Jul	33.09	319.64	141.09	75.36	53.4	1.77	1.238
Aug	52.1	357.6	178.65	63.78	35.7	1.46	1.722
Sep	36.67	210.37	133.22	58.34	43.8	0.79	0.800
Oct	0.83	315.38	56.63	63.63	112.4	0.00	0.000
Nov	3.14	101.36	23.95	31.47	131.4	1.59	0.146
Dec	0	49.01	14.1	18.45	130.9	−0.46	0.000
Belg	126.32	712.02	289.51	111.37	38.5	−3.10**	−7.00***
Kiremt	177.26	929.73	514.89	178.92	34.7	1.55	4.217***
Annually	424.35	1,421.5	920.84	254.21	27.6	−0.71	−2.010**

Notes: SD = standard deviation; CV% = coefficient of variation; MK = Mann–Kendall trend test; S.slope = Sen's slope; ** and ***are significant at 0.01 and 0.05 significance levels, respectively
Source: Author's own creation

country experience 500–600 mm of precipitation during the belg season, while the rest of the region experiences less. Similarly, Seleshi and Zanke (2004) suggest that a meteorological system originating from the Indian Ocean is responsible for the seasonal precipitation variations in the belg rainy season. Furthermore, Dereje (2012) found considerable belg precipitation variability in the Amhara region when compared to kiremt and yearly total precipitation from 1979 to 2008. The trend analysis of February and belg rainfall was significantly decreasing by a factor of −2.13 and −3.10, respectively (Table 5).

The study analyzed the variability and trends in minimum and maximum temperatures in the study area from 1993 to 2022 (Table 6). The lowest temperatures were recorded in December and April, while the hottest were in December (24.4°C) and March (32.4°C). The

Table 6. Descriptive statistics for monthly, *belg*, *kiremt* and annual temperatures in Dire Dawa district (1993–2022)

Variables	Minimum temperature							Maximum temperature						
	Min.	Max.	Mean	SD	CV%	MK	Sen's slope	Min.	Max.	Mean	SD	CV%	MK	Sen's slope
Jan	11.3	15.1	13.3	0.9	7.0	1.78	0.232	25.1	29.0	27.2	0.9	3.3	1.67	0.156
Febr	11.8	15.9	14.2	0.9	6.4	1.48	0.157	27.6	31.1	29.3	1.1	3.6	1.71	0.172
March	13.9	18.1	15.9	0.9	5.7	1.52	0.133	27.7	32.4	30.2	1.2	3.9	0.92	0.142
April	16.2	18.2	16.9	0.5	2.9	−0.13	0.066	26.7	31.3	29.1	1.3	4.5	1.11	0.150
May	16.1	17.4	16.7	0.3	2.1	−2.12**	−0.043	26.1	32.3	29.4	1.8	6.0	0.61	0.016
Jun	14.9	16.7	15.9	0.5	2.9	−2.04**	−0.079	26.2	31.3	29.3	1.2	4.2	−0.99	−0.003
Jul	14.9	16.5	15.9	0.5	5.3	−2.12**	−0.097	25.1	30.3	27.3	1.3	4.9	1.84	0.043
Aug	14.4	16.4	15.6	0.5	5.5	−1.22	−0.168	24.8	28.7	26.5	1.0	4.0	−0.64	0.017
Sep	14.6	16.9	15.9	0.6	5.9	−2.57	−0.230	24.8	29.4	26.8	1.2	4.4	1.66	0.039
Oct	13.1	16.2	14.9	0.7	7.2	−1.78	−0.150	23.9	30.5	27.3	1.6	5.8	0.13	0.053
Nov	12.1	15.2	13.5	0.8	6.5	0.62	0.015	24.8	29.6	26.9	1.3	4.8	0.88	0.034
Dec	10.1	15.3	12.4	1.2	4.1	1.29	0.096	24.4	28.6	26.5	1.0	3.7	2.08**	0.122
Belg	14.8	17.2	16.1	0.5	3.3	0.92	0.089	27.9	30.9	29.5	0.8	3.0	0.54	0.120
Kiremt	15.2	16.9	16.0	0.4	2.5	0.99	0.094	25.4	29.9	27.4	1.0	3.7	0.39	0.007
Annually	14.4	15.7	15.2	0.3	2.3	−5.06***	−0.013	26.6	29.6	27.9	0.7	2.8	3.28***	0.074

Notes: SD = Standard deviation; CV% = Coefficient of variation; MK = Mann–Kendall trend test; ** and ***are significant at the 0.05 significance level, respectively
Source: Author's own creation

coefficients of variation (CV%) did not differ significantly on a monthly, seasonal or annual basis. However, the yearly maximum and minimum temperatures were more variable than the mean minimum temperatures during the belg and kiremt seasons.

In Figure 3, the patterns of annual and seasonal rainfall totals over the research area are displayed. The annual maximum temperature showed a positive correlation, with 53.45% of variation in the belg season explained by temperature changes and 66.3% accounted for by other factors (Figure 4). These results are consistent with findings from other studies, such as those by Cheung *et al.* (2008), Seleshi and Zanke (2004) and Viste *et al.* (2013), which also found statistically non-significant trends in annual and seasonal rainfall totals in various parts of Ethiopia. These findings suggest that changes in the annual maximum temperature have a significant influence on the belg season. The higher R^2 values indicate a greater degree of predictability and a stronger relationship between the variables being analyzed.

3.3 Perceptions of farmers regarding climate change and variability

Figure 5 depicts that the majority (89%) of the interviewed households felt an increase in temperature. However, 4% of the respondents perceived a reduction in temperature. These results, verified by Jiri *et al.* (2015), indicated that more than 87% and 86% of the respondents noticed a rise in average temperature and a reduction in precipitation in the past 10–20 years in the Chiredzi district, Zimbabwe. Similarly, studies (Elias, 2020; Sisay *et al.*, 2018) reported that the majority of the interviewed farmers perceived rising temperatures and decreasing quantities of rainfall in southern Ethiopia. Another study by Asrat and Simane (2018) also found that more than 50% of the respondents observed a rise in temperature, whereas 42% and 25%, respectively, experienced no change and a lowering temperature. In this regard, the majority of smallholder farmers (90%) reported a decline in rainfall, while 4% reported trends of rainfall variability was increase and the remaining

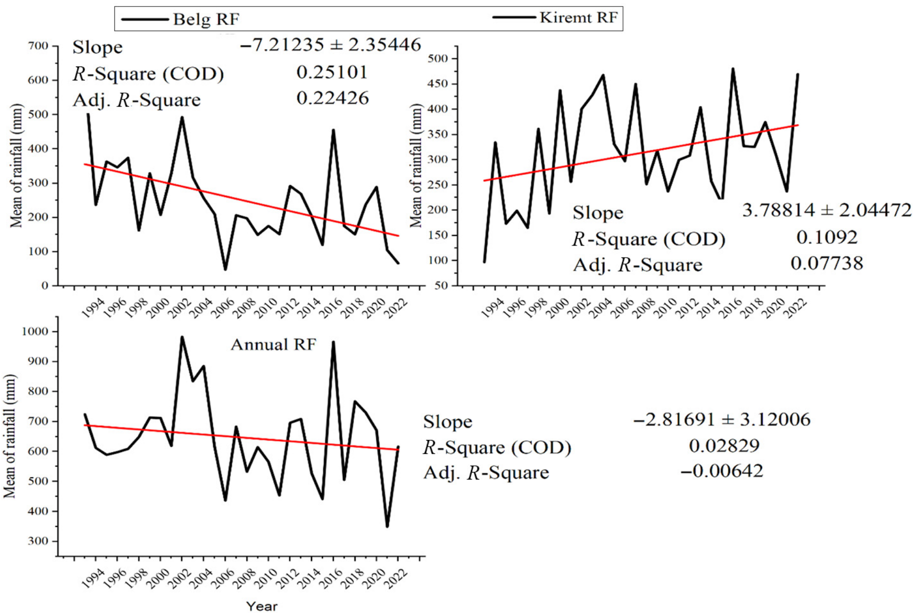

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Figure 3.
Annual, *kiremt and belg* rainfall trends of the study area in the period of 1993–2022

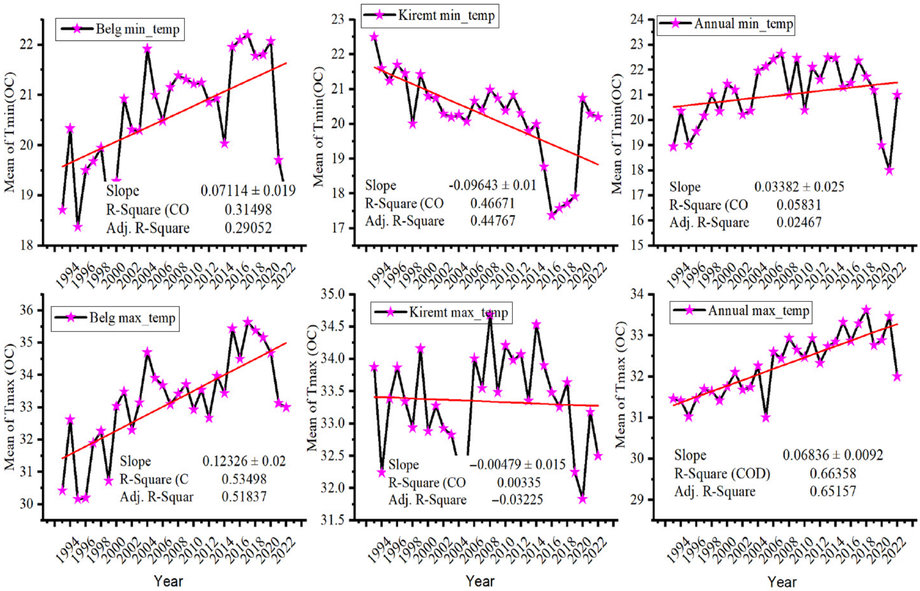

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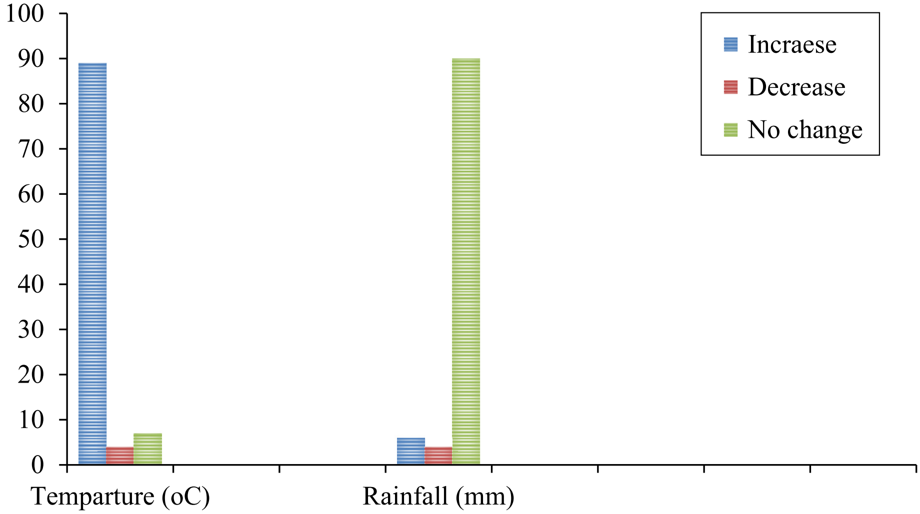
Figure 4.
Annual, *kiremt and belg* maximum and minimum temperature trends of the study area in the period of 1993–2022



Source: Author's own creation

Figure 5.
Farmers' perceived changes in rainfall and temperature in the study area

smallholder farmers or households perceived no changes in rainfall across the study area. According to the study by Arbuckle *et al.* (2013), Carlton *et al.* (2016) and Dang *et al.* (2014), farmers who saw climate change as a high-risk factor were more likely to adopt adaptation methods than those who considered the occurrences as typical fluctuations.

3.4 Climate change and variability observed in the Dire Dawa district

Figure 6 indicates that 85.13% of respondents reported that off-season precipitation occurs, while only 14.87% said that precipitation is not a problem in their area. However, only about 17.75% of respondents reported significant rainfall, while the remaining 82.25% said they had not observed significant rainfall, and 96.13% said there had not been enough rain in the study area. In contrast, only 24.37% of respondents reported difficulties with high winds, while the remaining 75.63% indicated that they had no such problem. The findings are in line with Feulner's (2017) argument that climate change is one of the most pressing and complex challenges that society faces today. It is a cross-cutting issue that affects different sectors and is linked to other global challenges, such as ensuring food security and promoting sustainable water use (Jagermeyr, 2020).

3.5 Barriers to climate change adaptation in the Dire Dawa district

Figure 7 shows the barriers faced by farmers who have adopted and not adopted climate change adaptation measures. The majority of respondents (25%) who had not yet implemented adaptation measures exhibited a lack of understanding. A shortage of capital resources also prevented 22% of individuals in the study area from taking adaptation measures (Figure 7). In this context, capital includes financial, physical and human capital, and having access to these resources may encourage farmers to be more flexible. A lack of farmed land (17%) consistently prevented the implementation of adaptation measures,

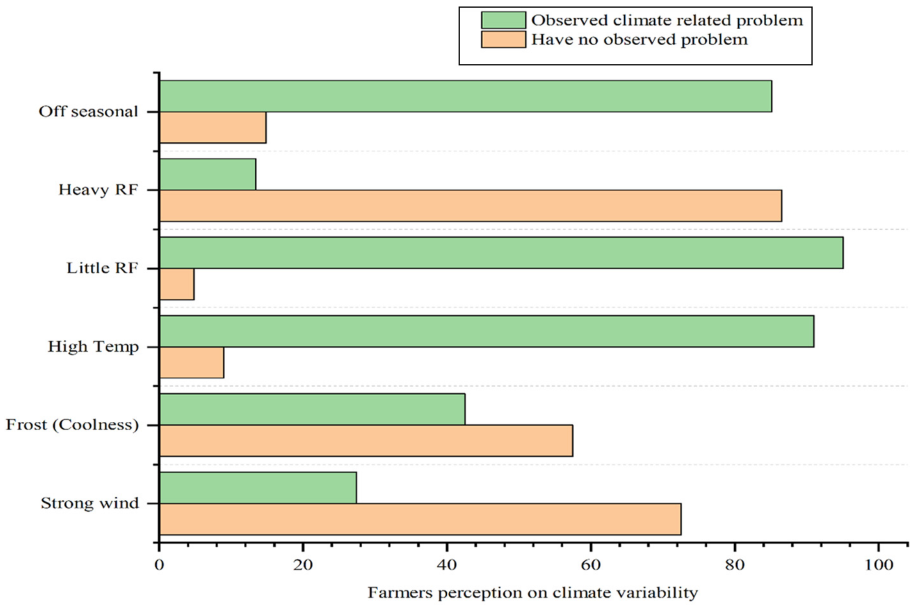
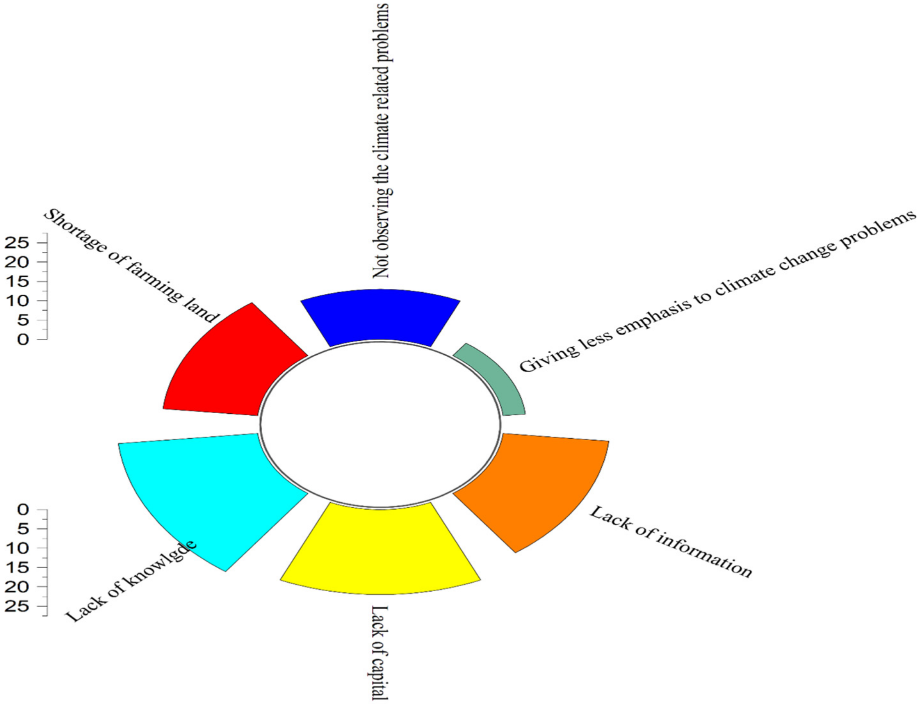


Figure 6. Farmers' responses to climate change and variability in the study area

Source: Author's own creation



Source: Author's own creation

Figure 7. Barriers to climate change adaptation in the study area

presenting significant obstacles for adaptation decisions throughout the study area. Other barriers to climate change adaptation in the Dire Dawa district include a lack of knowledge (19%) and insufficient emphasis (4%) from farmers themselves.

3.6 Determinants of smallholder farmers' adaptation options to climate change

Farm size (farmzse): Farm size had a significant and negative impact on methods of adoption with climate change, with land constraints being a significant factor. In the Dire Dawa area, farmers' adaptation decisions were significantly increased by 0.045%, which is less than *p*-values at the 5% confidence level (Table 7). These results were consistent with those of Bradshaw *et al.* (2004), who found that farm size had both positive and negative impacts on the adoption of technology. Households with larger farm sizes were more likely to apply more adaptation measures than farmers with smaller farm sizes, indicating that the larger the farm, the greater the share of area dedicated to different crop types as an adaptation method that farmers are likely to use. In the study area, the positive impact of improved crop and livestock production on smallholder farmers' adaptation strategies was found to be 0.096.

Livestock ownership (TLU): The ownership of livestock, as measured by tropical livestock units (TLU), was found to have a positive and significant impact on farmers' likelihood of applying adaptation strategies (Table 7). In particular, for each one-unit increase in TLU, the likelihood of applying adaptation strategies increased by 0.032% and 0.006% in relation to changing crop variety and soil and water conservation (SWC),

Table 7. Parameter estimates of the multinomial logit climate change adaptation model

Explanatory variable	Changing crop varieties Coef.	p-value	Improved crop and livestock Coef.	p-value	Soil and water conservation Coef.	p-value	Irrigation practice Coef.	p-value
sex	0.387	0.977	−0.492	0.720	14.9	0.985	−0.133	0.926
age	−0.0501	0.321	−0.034	0.511	−0.048	0.386	−0.024	0.657
edu	0.259	0.0014**	2.450	0.145	−4.23	0.987	0.916	0.591
familysze	0.387	0.080	0.539	0.018**	0.540	0.026**	0.443	0.060
farmsze	−1.859	0.045**	−3.54	0.096	−1.739	0.246	−1.714	0.233
TLU	2.143	0.032**	−0.087	0.427	0.801	0.006**	−0.106	0.345
credit	0.221	0.806	0.427	0.689	0.406	0.366	0.345	0.163
agriexes	−2.12	0.035**	−1.396	0.129	−2.00	0.033**	−1.675	0.095
onfarm	0.626	0.683	0.763	0.622	1.549	0.347	1.363	0.386
offarm	−0.914	0.315	−0.890	0.354	−0.165	0.875	−1.001	0.337
dmkt	0.134	0.199	0.186	0.090	0.286	0.043**	0.121	0.275
climinform	1.168	0.190	2.576	0.03**	3.164	0.190	2.130	0.045**
cons	0.564	0.895	−4.92	0.268	6.707	0.182	−2.13	0.643

Base category	No adaptation
Number of observations	146
LR $Chi^2(58)$	114.17
Log likelihood	−132.544
Prob > Chi^2	0.4150
Pseudo R-square	0.1313

Notes: * and **are significant at 1 and 5% probability levels, respectively
Source: Author's own creation

Table 8. Marginal effects from the multinomial logit climate change adaptation model

Explanatory variable	Changing crop varieties dy/dx	p-value	Improved crop and livestock dy/dx	p-value	Soil and water conservation dy/dx	p-value	Irrigation practice dy/dx	p-value	No adaptation dy/dx	p-value
sex	−0.091	0.871	−0.222	0.018	0.398	0.974	−0.074	0.976	−0.011	0.985
age	−0.053	0.819	0.001	0.853	0.001	0.467	0.003	0.578	0.002	0.642
edu	−0.176	0.972	0.520	0.789	−0.36	0.869	0.049	0.98	−0.030	0.957
familysze	−0.019	0.792	0.033	0.835	0.003	0.010*	0.002	0.0008*	−0.019	0.586
farmsze	−0.187	0.267	−0.024	0.941	0.013	0.794	0.100	0.835	0.099	0.735
TLU	0.011	0.457	−0.006	0.883	−0.001	0.712	−0.007	0.828	0.003	0.597
credit	−0.053	0.729	0.104	0.713	0.001	0.991	−0.036	0.763	−0.015	0.76
agriexes	0.151	0.027*	−0.068	0.041*	0.036	0.691	−0.099	0.907	0.052	0.193
onfarm	−0.079	0.894	−0.014	0.979	0.020	0.343	0.108	0.859	−0.036	0.555
offarm	0.022	0.034*	−0.008	0.987	0.019	0.005**	−0.027	0.624	0.038	0.821
dmkt	−0.005	0.971	0.012	0.925	0.004	0.281	−0.005**	0.931	−0.006	0.13
climinfor	−0.019	0.906	0.044	0.853	0.004	0.544	0.042	0.827	−0.071	0.659

Source: Author's own creation

respectively ($p < 0.05$). These findings align with a previous study by Tazeze *et al.* (2012), which emphasized the significant role of animals in managing soil fertility by providing traction (especially oxen) and manure, as well as serving as a source of income to purchase improved crop varieties.

Agricultural extension services (agriexes): The study found that agricultural extension services had a negative impact on farmers' methods of adapting to climate change in the study area. The likelihood of changing crop varieties and adopting soil-water conservation practices increased significantly for farmers by 0.033% at *p*-values of 1% and 5% confidence levels. This suggests that the agricultural worker field is crucial in farmland to improve farmers' lifestyles by providing training on changing crop varieties, enhancing crop–livestock and boosting soil-water conservation practices.

On farm (onfarm): The study found that there is a growing likelihood of adopting SWC practices as part of climate change adaptation strategies in the research area. Farmers with greater financial capacity, according to Deressa *et al.* (2008), are less risk-averse in crop production and have access to a longer time horizon, which may explain the positive impact of farm income on climate change adaptation options. The findings of Mulatu (2013) also suggest that increased household farm income increases the likelihood of adapting to climate change through soil protection, irrigation and animal production.

Access to climate information (climinform): The study found that access to climate information significantly increases by 0.03% and 0.045% the likelihood of using improved crop–livestock production and irrigation practices, respectively (Table 7). This revealed the need for stronger institutional support to encourage alternative climate change adaptation strategies. This aligns with previous research (Deressa *et al.*, 2009; Mulatu, 2013) indicating that improved climate information supports crop diversification and planting date adjustments.

3.7 Marginal effects of the climate change adaptation option

The study uses the Stata-13 command mfx to calculate the size of the effect after conducting a MNL regression with marginal impact. The results show that the sex of the household head (*sex*) has a positive and significant effect on the adoption of improved crop livestock production, which implies that being a female household head has a positive effect on crop and livestock productivity, soil-water conservation and irrigation practice adaptation strategies. Off-farm income (*offarm*) has a significant positive impact on the adoption of crop variety and soil-water conservation by 0.034% and 0.005%, respectively, with higher levels of income making farmers more likely to adopt these practices. Family size (*familysze*) also has a positive and significant impact on soil-water conservation and irrigation adaptation strategies, with larger families more likely to adopt these practices. Agricultural extension services (***agriexes***) have a significant positive impact on crop varieties and soil-water conservation techniques by 0.027% and 0.041%, respectively, at the $p < 0.05$ confidence level (Table 8).

3.8 Drought characterization indices

3.8.1 Standard precipitation index. Figure 8 displays the results of the standardized precipitation index (SPI) for the Dire Dawa district areas over a 12-month period. The study found that the values of SPI3 for nine months of various years indicated exceptionally wet climatic conditions, while five months showed extremely dry conditions in the research area, as shown in Figure 8. Additionally, the research area experienced exceptionally wet conditions for six, four and eight months during the years 1993 and 2022, respectively, as indicated by the standard precipitation index for 6, 9 and 12 months (SPI6, SPI9 and SPI12) time scales. In contrast, the SPI6, SPI9 and SPI12 showed severely dry weather for eight, seven and five months, respectively, indicating that no rainfall during those months increased the likelihood of drought. This aligns with the findings of earlier studies, including (Gebreyesus *et al.*, 2020; Tigkas *et al.*, 2013; Trnka *et al.*, 2016), which have demonstrated the harmful impact of droughts on natural resources and agricultural production.

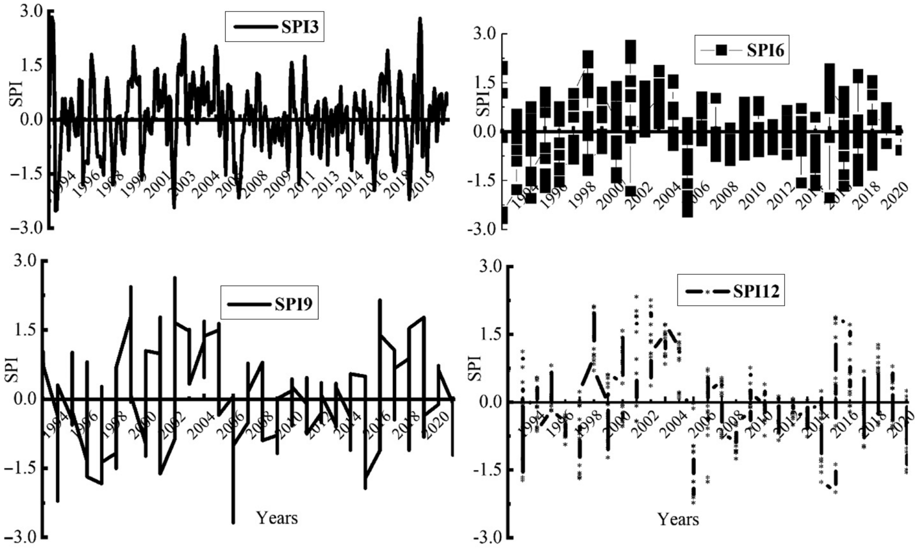
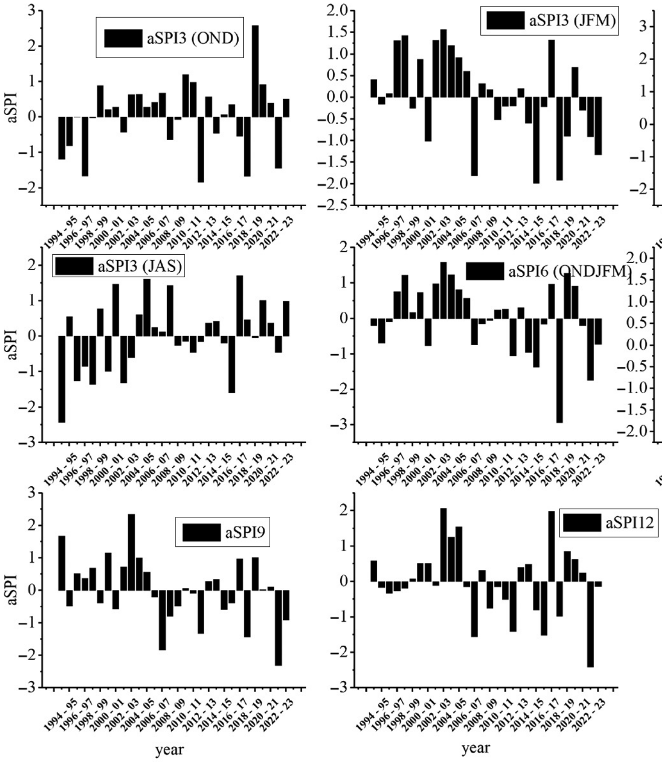


Figure 8.
Standard precipitation index at each 12 months of each year of 1993–2022

Source: Author's own creation

3.8.2 Agricultural standardized index. An appropriate reference period for agricultural drought identification for the study area in 2006–07, 1993–04 and 2017–18 was the extreme agricultural standardized drought index by aSPI3 in April, May and June (AMJ) and July, August and September (JAS). Similarly, aSPI6 increased in the October, November, December, January, February and March (ONDJFM) months, respectively. In 2021–22, the values of the aSPI9 and aSPI12 time scales of months indicate extreme drought index by a factor of −2.32 and −2.41 over the study area (Figure 9). The results were substantiated by Li *et al.* (2017), Wegren (2011) and Zhao (2010) the fact that drought is widely recognized as a major natural hazard in the agricultural sector, which often results in significant challenges to food security and has subsequent economic and social impacts. The severity of agricultural drought can be evaluated by measuring its impact on vegetation, considering factors such as plant growth, crop yield and other related parameters.

3.8.3 Reconnaissance drought index. The result shows that the RDI3 values of Dire Dawa station were severe drought in the time period of 1996–07, 2011–012 and 2017–18 by a factor of −1.66, −1.83 and −1.67 values under RDI3 (OND) and −1.77 and −1.93 in 2006–7 and 2014–15 by RDI3 (JFM), again −1.98 and −1.74 in 2006–7 and 2015–16 under RDI3 in AMJ and JAS months of the years, respectively (Figure 10). This suggests that smallholder agricultural activities have been significantly impacted by drought over the past 30 years, resulting in decreased yields of grain crops such as sorghum and maize, which are the primary cereal crops produced. Similarly, the months of ONDJFM and AMJJAS showed extreme and severe drought index values of −2.88 and −1.96, respectively, based on the RDI6 over the study area. In the years 2021–22, the drought contribution values under RDI9 and RDI12 were −2.30 and −2.44, respectively. The results are consistent with the findings of Gebreyesus *et al.* (2020), Tigkas *et al.* (2013) and Trnka *et al.* (2016), which demonstrated the negative impact of drought on natural resources and agricultural production.



Source: Author's own creation

Figure 9
Agricultural standardized precipitation index (aSPI) of the Dire Dawa area

4. Conclusion and recommendation

This research aimed to explore smallholder farmers' perceptions of climate change and its adaptation options in the Dire Dawa administration zone, eastern Ethiopia. The results showed that rainfall trends decreased by −7.00 and −2.010, significant at the 5% confidence level from 1993 to 2022, while maximum temperature trends were increasing in all months except June and August. Smallholder farmers' perceptions also confirmed an increase in temperature and a decrease in rainfall trend in the past 30 years. Smallholder farmers are negatively impacted by climate-related concerns such as weed and pest infestations, disease prevalence and the significant risk of crop loss from droughts.

Farm size had a significant and negative impact on methods of coping with climate change, with land constraints being a significant factor. Livestock ownership (TLU) had a positive and significant impact on farmers' likelihood of applying adaptation strategies. Agricultural extension services had a negative impact on farmers' methods of adapting to climate change in the study area. Access to climate information significantly increased the likelihood of using improved crop–livestock production and irrigation practices. The study also found that the sex of the household head had a positive effect on the adoption of improved crop–livestock production. Off-farm income and family size also had a positive and significant impact on soil-water conservation and irrigation adaptation strategies. The SPI6, SPI9 and SPI12 showed severe dry weather for eight, seven and five

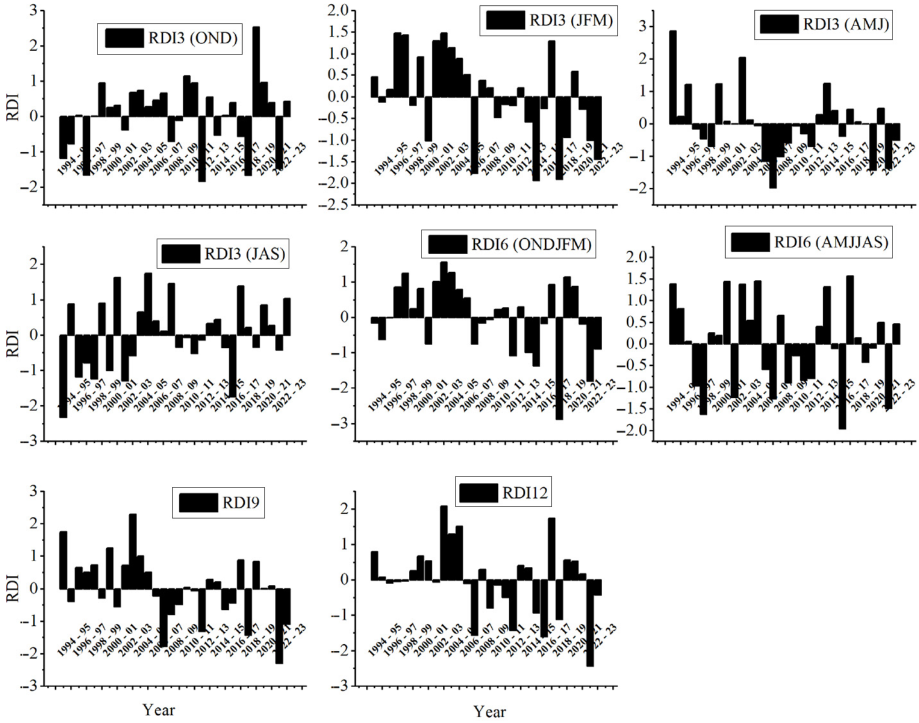


Figure 10. Reconnaissance drought index (RDI) of the Dire Dawa area

Source: Author's own creation

months, indicating no rainfall and increased drought likelihood. Dire Dawa station experienced severe drought multiple times, with RDI3 values ranging from −1.66 to −1.67. Government policies should promote research, agricultural extension services and technology development to enable farmers to adapt to climate and environmental changes.

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