THE THESIS OF THE PHD DISSERTATION

MESFIN BEKELE GEBBISA

Gödöllő, Hungary

September 2026



Hungarian University of Agriculture and Life Sciences

Pastoralist Household Vulnerability to Climate Change and Variability-Induced Shock: Adaptation Mechanisms in the Rayitu district, Southeastern Ethiopia

PhD Dissertation

by

Mesfin Bekele Gebbisa

Gödöllő, Hungary

September 2026

Name of the PhD School:	Doctoral School of Economic and Regional Sciences
Discipline:	Regional Science
Head of the PhD School:	Prof. Dr. Viktória Szente, PhD MATE, Institute of Agricultural and Food Economics
Supervisor(s):	Prof.Dr. Zsuzsanna Bacsi, PhD (Major Supervisor) MATE, Institute of Agricultural and Food Economics Dr. Habil Zsolt Hollósy, PhD (Co-Supervisor) Associate Professor, ELTE, Institute of Economics

……...	…….
Approval of the Doctoral School Head	Approval of the Supervisor (s)

TABLE OF CONTENTS

TABLE OF CONTENTS **0**
1.INTRDUCTION **1**
1.1 Research background and Problem statements 1
1.2 Research Objectives and hypotheses 2
2. MATERIALS AND METHODS **4**
2.1 Research strategies 4
2.2 Method of Data collection 4
2.3 Conceptual framework 6
2.4 Data analysis 7
3. RESULT AND DISCUSSION **10**
3.1 Model output 10
3.2.1 Climate variability and trends 10
3.2.2 Drought 14
3.2.3 Households' perception of climate change 17
3.2.4 Household vulnerability 21
3.2.5 Determinants of coping and adaptation strategies 28
3.2 Result of Hypothesis testing 33
4. CONCLUSIONS AND RECOMMENDATIONS **38**
4.1 Conclusion 38
4.2 Policy Recommendation and Implication 39
4.3 Limitation and direction for future research 40
5. NEW SCIENTIFIC RESULTS **42**
6. LIST OF PUBLICATIONS **45**
7. REFERENCES **46**

1.INTRDUCTION

1.1 Research background and Problem statements

Pastoralism is one of the world's oldest livelihood systems, supporting millions of people across about 25 percent of the Earth's surface and practiced in nearly 75 percent of countries, particularly in Africa's dryland regions (Barrow, 2022; Mbow et al., 2019). Pastoral production systems cover about 43 percent of Africa's land surface and support nearly 20.37 percent of the continent's population, while contributing significantly to food security, employment, trade, and national economies, particularly in East Africa and the Horn of Africa (AU, 2010; Bacsi et al., 2023). Beyond its economic importance, pastoralism also contributes to biodiversity conservation, vegetation management, and ecosystem sustainability through extensive grazing systems (Manzano et al., 2021). In many African countries, pastoral landscapes coexist with wildlife conservation areas and ecotourism destinations (CELEP, 2017).

Ethiopia is among the major pastoral countries in East Africa, with pastoral and agro-pastoral systems covering about 61 percent of the national land area (Gebremeskel et al., 2019; Mohamed, 2019). Pastoral households mainly depend on livestock such as cattle, camels, goats, and sheep for food, income, transport, savings, and cultural identity (Mohamad, 2019). The sector contributes significantly for 10-40 percent of Ethiopia's GDP, 30-35 percent of agricultural GDP, 90 percent of Ethiopia's livestock exports, 38 percent of milk production, and 34 percent of national meat supply (Abduletif, 2019; Guye et al., 2023; ICPALD, 2020; MoA, 2012; Shapiro et al., 2017). Pastoral rangelands also provide ecological services and support indigenous knowledge systems related to natural resource and livestock management (Alemu and Worku, 2017).

Despite these contributions, pastoral areas in Ethiopia remain marginalized, with limited access to infrastructure and basic services such as education, health, water, markets, and electricity (AU, 2010; ICPALD, 2020). Pastoralism has long been viewed as backward and environmentally unsustainable, leading to policies favouring sedentarisation, irrigation expansion, and crop agriculture (Gebremeskel et al., 2019; Mohamed, 2019). Although Ethiopian policies since the 1990s formally recognized pastoral land rights and development needs (FDRE, 1995; NPC, 2016), implementation gaps remain substantial, while restrictions on mobility and communal grazing continue to weaken traditional pastoral systems (Teka et al., 2022).

These challenges are increasingly aggravated by climate change and climate variability. Rising temperatures, erratic rainfall, recurrent droughts, floods, environmental degradation, and resource conflicts are intensifying pressure on pastoral livelihoods (FDRE, 2021; Mera, 2018). Since pastoral livelihoods depend heavily on climate-sensitive resources such as water and pasture, climate shocks directly affect livestock productivity, food security, and household resilience (Gatew and Guyo, 2024; Kimutai et al., 2025). In Ethiopia drought in southern and southeastern Ethiopia severely affected pastoral communities through livestock deaths, migration, school dropout, and worsening food insecurity (Mera, 2018).

In response to climate change, pastoral households employ various coping and adaptation strategies, including herd diversification, seasonal mobility, drought-tolerant livestock, irrigation, and livelihood diversification (Berhanu and Beyene, 2015; Duba et al., 2021; Gebbisa and Bacsi, 2025). However, existing studies still face methodological gaps, as many rely mainly on household perceptions without integrating long-term climate evidence and often overlook pastoral-specific factors such as mobility, grazing access, conflicts, and indigenous institutions (Debela et al., 2015; Megersa et al., 2014). In addition, most studies use multinomial logit models that assume households adopt only one strategy, despite pastoralists commonly practicing multiple and interrelated adaptation strategies simultaneously (Mengistu & Haji, 2015; Ndiritu, 2021).

Furthermore, pastoral climate research in Ethiopia remains geographically uneven (Gebremeskel et al., 2019; NPC, 2016), as about 73% of studies conducted between 2014 and 2025 focused on highland agricultural areas, while only 27% addressed pastoral and agro-pastoral regions due to data, security, and logistical constraints. Consequently, important policies, methodological, and spatial gaps continue to limit effective climate adaptation planning in pastoral areas.

Therefore, this study examines pastoral households' vulnerability to climate change and variability-induced shocks as well as their coping and adaptation strategies in Rayitu District, Southeast Ethiopia. The study aims to generate empirical evidence that can support more effective and context-specific climate adaptation policies for pastoral communities.

1.2 Research Objectives and hypotheses

The general objective of this study is to examine pastoralist households' vulnerability to climate change and variability-induced shocks and Adaptation

strategies in the Rayitu district, Southeast Ethiopia**.** The specific objectives of the study were defined as follows:

1. To analyse the long-term variability and trends in precipitation and temperature and their correlation between them in the study area
2. To quantify the inter-annual precipitation distribution and the dominance of mild drought
3. To analyse the indicators of perceptions and to identify the key determinants that influence household perceptions of climate change
4. To measure pastoralists' vulnerability to climate change at the household level and identify its determinants in the study area.
5. To examine local pastoral household coping and adaptation mechanisms towards climate change and identify its determinants in the study area.

Based on the above objective the following hypotheses guided the study:

1. The monthly precipitation varies by seasons without an annual precipitation trend
2. Annual and seasonal temperatures show a positive trend and temperatures are negatively correlated to precipitation.
3. Annual precipitation is concentrated in specific months, and the occurrence of mild drought is dominant
4. A higher proportion of pastoralist households perceive direct (meteorological) climate impacts than indirect (livelihood-related) climate change indicators.
5. Economic and environmental/physical capital endowments have stronger magnitude effects on household perception than socio-demographic and institutional factors.
6. The combined effects of human and financial capital are expected to have a stronger influence on household vulnerability than natural and physical capital.
7. Higher human capital endowments (education, training, livelihood experience, health status) reduces the probability of high vulnerability of pastoralist household.
8. Human, social, financial, natural, and physical capital have significantly different effects on pastoral households' coping and adaptation strategies.

2. MATERIALS AND METHODS

2.1 Research strategies

This study employed a cross-sectional research strategy with a mixed-methods approach, combining quantitative and qualitative techniques to capture the complex interactions between climate variability and pastoral livelihoods. The use of both approaches enhanced the depth, credibility, and reliability of findings through triangulation (Creswell, 2014; Johnson et al., 2007).

This study employed both primary and secondary data sources. Primary data were collected through household surveys, focus group discussions (FGDs), key informant interviews (KIIs), and direct observation. A household survey involving 351 pastoral households was conducted during April–May to assess climate variability, drought, vulnerability, perception, coping, and adaptation strategies. The survey also captured socio-demographic characteristics and determinants of adaptation practices.

To complement the survey findings, six FGDs involving 72 participants and 36 KIIs with local leaders, experts, and community members were conducted using structured and open-ended discussions on climate change experiences, vulnerability, pastoral livelihoods, and adaptation strategies. In addition, direct observation was undertaken to assess livelihood practices, household resilience, and coping mechanisms, supported by field notes and photographs.

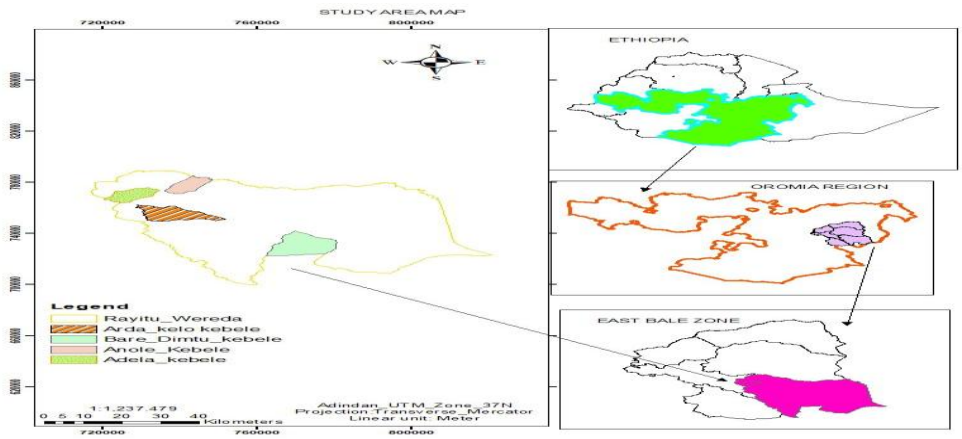
Secondary climate data, including rainfall and temperature records from 1980 to 2024, were obtained from the Meteoblue database to support trend, variability, and drought analyses. Finally, the study applied data triangulation by integrating information from surveys, FGDs, KIIs, observations, and secondary sources to improve the reliability, validity, and comprehensiveness of the findings (McDermaid and Barnstable, 2001).

2.2 Method of Data collection

For this study, the researcher used multi-stage sampling techniques that incorporate both purposive and random sampling techniques. Rayitu was purposively selected from the existing five pastoral districts of the Eastern Bale zone for this study because it is predominantly pastoral, highly vulnerable to recurrent droughts, and representative of the ecological and socio-economic characteristics of the wider zone. Furthermore, its accessibility and local

institutional support made it feasible for intensive data collection within the resource and time constraints of this research.

Figure 1: Map of Study area



Source: Author's own construction

Rayitu district has a total population of 111,235, organized into 21,927 households (OPEDC, 2025). From the 19 kebeles in Rayitu district, four kebeles i.e Arda Kalo, Adela, Anole, and Bara Dimtu were purposively selected. These sites were chosen because they represent predominantly pastoral and agro-pastoral communities, are highly vulnerable to recurrent drought, and were accessible for data collection. Their selection also reflected recommendations from the district pastoral and rural development office and ensured feasibility within the study's time and resource constraints. The study determined the sample size using the Kothari (2004) equation. The equation helps determine the sample size when the population size is finite. Let's break down the equation:

$$n = \frac{z^2.p.q.N}{e^2(N-1) + z^2.p.q} \qquad \text{(Eq.1)}$$

where,

z: values of standard variant at 95% confidence interval (Z = 1.96).

p: the estimated proportion of an attribute that is present in the population.

q: the estimated proportion of an attribute that is not present in the population.

e: margin of error considered is 5 % for this study

N: total population

$$n = \frac{(1.96)^2(0.5)(0.5)(4064)}{(.05)^2(4064-1) + (1.96)^2(0.5)(.5)} = 351$$

The four selected kebeles, Arda Kalo, Adela, Anole, and Bara Dimtu, have a combined total of 4,064 households (OPEDC, 2025). Based on the formula for determining sample size, the required sample consisted of 351 households. Accordingly, the sample respondents were proportionally distributed across the four kebeles in line with their respective household numbers, using Equation (2).

$$n_i = \frac{N_i}{N} * n \qquad \text{(Eq. 2)}$$

where the variables n_i, N_i, N, and n represent the sample households from kebele i, the total households in kebele i, the total households in all selected kebeles (4,064), and the total sample size (351), respectively.

Table 1: Household sample respondents at the kebeles level

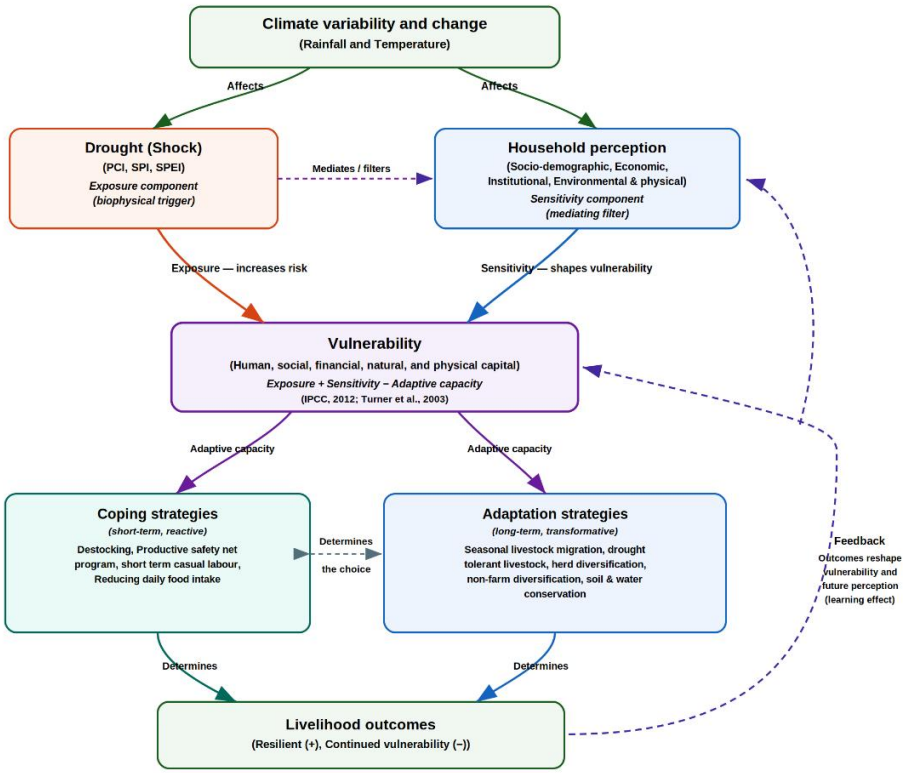
S.N	Name of village	Number of total households	Number of sample households
1	Arda Kalo	954	81
2	Adela	990	84
3	Anole	960	83
4	Bara Dimtu	1160	103
Total		**4064**	**351**

Source: Author's own construction, based on OPEDC (2023)

2.3 Conceptual framework

This study integrates three complementary perspectives: the Vulnerability–Sensitivity–Resilience (VASS) framework (Turner et al., 2003), the Exposure–Sensitivity–Adaptive Capacity (ESAC) framework (Lavell et al., 2012), and the Sustainable Livelihoods Framework (SLF) (Scoones, 1998; DFID, 1999). The framework explains how climate variability and drought affect pastoral households through exposure, vulnerability, and perceptions, shaping their coping and adaptation strategies and ultimately their livelihood outcomes. These outcomes may further influence future vulnerability and perceptions of climate risks as explained in Figure 6.

Figure 2: Conceptual framework of the study



Source: Author's own computation

2.4 Data analysis

This study analyzed primary survey data and secondary climate data using descriptive statistics, inferential techniques, a climate trend and magnitude analysis model (Mann–Kendall statistical test, Sen's slope estimator, the coefficient of variation, a correlation coefficient, and drought indices), and econometric models. Data were first edited, coded, classified, and summarized before analysis using IBM SPSS 29, Stata 17, XLSTAT 2025, and DrinC software as summarized and indicated in table 2.

Table 2: Method of Analysis

Objective	Hypothesis	Model applied	Software
1: To analyse the long-term rainfall and temperature variability and trends in the study area	H1: The monthly precipitation varies by seasons without an annual precipitation trend	Mann–Kendall Test (Mann, 1945; Kendall, 1975)	XLSTAT 2025
		Sen's Slope Estimator (Sen, 1968)	
	H2: Annual and seasonal temperatures show a positive trend and temperatures are negatively correlated to precipitation	Coefficient of Variation (Pearson, 1896)	IBM SPSS 29
		Pearson Correlation (Pearson, 1896)	
2: To assess drought and rainfall concentration characteristics in the study area	H3: Annual precipitation is concentrated in specific months, and the occurrence of mild drought is dominant	Precipitation Concentration Index (Oliver, 1980)	DrinC
		Standardized Precipitation Index (McKee et al., 1993)	
		Standardized Precipitation Evapotranspiration Index (Vicente-Serrano et al., 2010)	
3: To examine pastoral households' perception of climate change and its determinants	H4: A higher proportion of pastoral households perceive direct (meteorological) climate impacts than indirect (livelihood-related) climate change indicators	Chi-square Test (Pearson, 1900)	IBM SPSS 29

Objective	Hypothesis	Model applied	Software
	H5: Economic and environmental/physical capital endowments have stronger magnitude effects on household perception than socio-demographic and institutional factors	Binary Logistic Regression (Cox, 1958)	IBM SPSS 29
4: To measure household vulnerability to climate change and identify its determinants	H6: The combined effects of human and financial capital are expected to have a stronger influence on household vulnerability than natural and physical capital	Principal Component Analysis (Pearson, 1901; Hotelling, 1933)	Stata 17
	H7: Higher human capital endowments (education, training, livelihood experience, health status) reduce the probability of high vulnerability of pastoralist households	Ordinal Logit Model (Greene, 2002)	Stata 17
5: To examine local pastoral household coping and adaptation mechanisms towards climate change and identify its determinants	H8: Human, social, financial, natural, and physical capital have significantly different effects on pastoral households' coping and adaptation strategies	Multivariate Probit Model (Ashford & Sowden, 1970)	Stata 17
		Marginal Effects (Hassan, 1996)	Stata 17

Source: Authors own construction based on reviewed literature

3. RESULT AND DISCUSSION

This section presents and discusses the main research findings, summarizing results in relation to the identified gaps, objectives, and hypotheses. The results are organized into tables and figures, and the study interprets the evidence within the context of the literature and local research area. The outline of the key findings and discussions is presented below.

3.1 Model output

This section presents the study's empirical results. It first examines climate trends and their magnitude using the Mann–Kendall test, Sen's slope estimator, coefficient of variation, correlation analysis, and drought indices. It then presents the econometric results concerning household perceptions, vulnerability, and coping and adaptation strategies. Together, these analyses provide evidence for addressing the study's objectives and testing its hypotheses.

3.2.1 Climate variability and trends

The climate analysis examined rainfall variability, temperature trends, and rainfall–temperature correlation in Rayitu district using the Mann–Kendall trend test, Sen's slope, and coefficient of variation. The findings are discussed below as follows:

As the finding indicated in Table 3, monthly rainfall in the Rayitu district is highly irregular, with most months showing coefficients of variation above 100%, reflecting very low reliability typical of Ethiopia's arid lowlands. The largest fluctuations occur in January, February, June, and December, while only April (CV = 38.2%) and May (54.5%) are relatively stable, corresponding to the short spring "locally Belg" rains. Trend analysis using the Mann–Kendall test indicates no long-term consistent change, except for a significant decline in September ($\tau = -0.234$, $p = 0.024$) and an increase in November ($\tau = 0.263$, $p = 0.011$). These patterns align with recent regional studies, including Duba (2022), Sahilu et al. (2024), and Dejene et al. (2023), which document erratic rainfall and late season increases in Borana, East Bale, and other lowland areas. Overall, Rayitu's district rainfall variation reflects a broader southern Ethiopian climate signal characterized by irregular precipitation and a gradual tendency toward seasonal drying.

Table 3: Mann Kendall trend test for rainfall (1980-2022)

Variable	Minimum	Maximum	Mean	SD	CV	Kendall's tau	p-value	Sen's slope
January	0.000	51.900	2.822	8.066	285.80	-0.080	0.472	0.000
February	0.000	40.300	4.772	10.638	222.93	-0.150	0.176	0.000
March	0.000	230.000	38.669	47.650	123.23	0.007	0.953	0.023
April	24.700	255.600	121.37	46.376	38.21	-0.095	0.363	-0.504
May	6.600	140.100	58.056	31.620	54.46	-0.147	0.156	-0.516
June	0.000	21.200	2.764	4.733	171.22	-0.107	0.312	-0.008
July	0.000	31.800	6.578	7.073	107.52	-0.040	0.703	-0.014
August	0.000	16.200	3.302	3.718	112.60	-0.052	0.625	-0.010
September	0.300	53.800	8.862	9.764	110.17	-0.234	0.024	-0.179
October	14.400	283.100	85.864	52.70	61.38	0.127	0.221	0.705
November	1.900	280.500	54.978	47.27	85.99	0.263	0.011	1.044
December	0.000	74.400	10.280	16.99	165.34	-0.200	0.060	-0.063
Winter	0.000	90.900	17.874	22.68	126.91	-0.195	0.060	-0.157
Spring	79.100	401.900	218.100	72.222	3.11	-0.188	0.070	-1.453
Summer	0.700	33.800	12.644	9.219	72.91	-0.011	0.922	-0.016
Autumn	19.500	459.400	149.70	87.72	58.60	0.194	0.062	1.934
Annual	168.900	813.100	398.32	120.23	30.18	-0.046	0.660	-0.463

Source: Authors own computation using XLSTATA version 2024

The seasonal rainfall trend analysis (Table 3) shows that the spring season (Belg), the district's main growing season, is the most stable (CV = 33.1%) but displays a nearly significant declining trend ($\tau = -0.188, p = 0.07$), indicating a gradual drying of the rangeland and water source base. Similarly, winter rainfall exhibits the highest variability (CV = 126.9%) and a comparable decreasing tendency ($p = 0.06$), reflecting growing uncertainty during the driest months. In contrast, autumn rainfall (Sep–Nov) indicates a mild increasing pattern ($\tau = 0.194, p \approx 0.06$), implying a possible intensification of the short rains. Summer remains statistically stable. Despite this seasonal contrast, annual rainfall shows no significant long-term trend ($p = 0.66$); the data indicates that the issue is not about rain quantity but about distribution and reliability.

The decline in spring rainfall confirms findings by Asfaw et al. (2018) and Tadesse et al. (2024) across Ethiopia's arid zones, which also linked the Belg rainfall decline to delayed onset, early cessation, and food insecurity. The high variability and drying of the winter months mirror the observations of

Abrham & Mekuyi (2022) and Sahilu et al. (2024) in Borana and Guji, where erratic early-season rainfall impacts water and forage availability. On the other hand, the autumn rainfall increase is consistent with Worku et al. (2022) and Gebbisa & Bacsi (2025), who reported enhanced short rains in the East Bale and Borana regions, possibly linked to changes in local atmospheric circulation. Moreover, the absence of an annual rainfall trend agrees with Dejene et al. (2023) and Gebbisa & Bacsi (2025), emphasizing that Ethiopia's climate instability arises mainly from intra-seasonal inconsistency, not diminishing total rainfall.

The analysis of temperature trends in the Rayitu district from 1980 to 2024 indicates a consistent and statistically significant warming pattern across minimum, maximum, and mean temperature indices. Table 4 indicated that the steepest rise in minimum temperature (Tmin) occurs in October (0.056 °C yr^{-1}), followed by August (0.038 °C), June (0.037 °C), and May (0.033 °C), showing progressively warmer nights and reduced nocturnal cooling. Monthly variability in minimum temperature (Tmin) is highest in October (CV = 5.67), reflecting unstable night-time conditions during the transition between wet and dry seasons. Likewise, maximum temperature (Tmax) shows strong and statistically significant warming across most months, with the highest rates recorded between April and September (ranging from 0.036 °C to 0.047 °C yr^{-1}). This pattern aligns closely with previous studies from semi-arid Ethiopia by Tofu & Mengistu (2023) and Alemayehu et al. (2024), which identified the same mid-year period as the peak warming phase.

Table 4: Mann Kendall trend test for temperature (1980-2024)

Variable	Minimum average			Maximum average			Mean Average		
	CV	Kendall's tau	Sen's slope	CV	Kendall's tau	Sen's slope	CV	Kendall's tau	Sen's slope
January	4.67	0.204**	0.021	2.32	0.236**	0.017**	2.31	0.335*	0.021
February	4.5	0.287*	0.026	2.44	0.358*	0.029*	2.68	0.372*	0.028
March	4.54	0.125	0.015	4.04	0.145	0.02	4.17	0.164	0.021
April	4.21	0.309*	0.028	4.16	0.269*	0.036	4.31	0.311*	0.034
May	3.65	0.436*	0.033	3.89	0.352*	0.045	3.98	0.39*	0.04
June	3.69	0.463*	0.037	3.89	0.311*	0.041	3.76	0.42*	0.041
July	3.23	0.337*	0.024	3.45	0.317*	0.037	3.29	0.343*	0.032
August	3.21	0.539*	0.038	3.15	0.436*	0.047	3.03	0.529*	0.043
September	3.48	0.527*	0.041	2.57	0.512*	0.043	2.98	0.584*	0.045
October	5.67	0.418*	0.056	3.65	0.2**	0.021	4.3	0.317*	0.038

Variable	Minimum average			Maximum average			Mean Average		
	CV	Kendall's tau	Sen's slope	CV	Kendall's tau	Sen's slope	CV	Kendall's tau	Sen's slope
November	4.31	0.347*	0.028	4.42	-0.024	-0.003	4.12	0.063	0.007
December	4.97	0.129	0.016	3.88	0.194	0.022	3.79	0.20**	0.021
Winter	2.89	0.366*	0.024	1.85	0.378*	0.023	1.85	0.479*	0.025
Spring	3.21	0.366*	0.028	3	0.366*	0.035	3.19	0.366*	0.035
Summer	3.01	0.499*	0.033	2.87	0.446*	0.04	2.92	0.497*	0.038
Autumn	3.69	0.57*	0.042	2.66	0.24**	0.022	2.99	0.402*	0.032
Annual	2.51	0.614*	0.031	1.84	0.545*	0.032	2.13	0.634*	0.034

Source: Authors own computation using XL Stata Version 2025, * and ** represents 1 % and 5 % significant level respectively

According to table 4, seasonally the warming is most pronounced in the summer season (0.040 °C yr^{-1}), followed by spring (0.035 °C) and autumn (0.032 °C), while winter remains the coolest but still exhibits a positive trend (0.025 °C yr^{-1}). The annual mean temperature has increased at an average rate of 0.031–0.034 °C per year, equivalent to approximately 0.3 °C per decade, confirming the persistence of long-term warming. These results strengthen the national and regional findings of Shigute et al. (2023), Tadesse et al. (2024), and Aytenfisu et al. (2024), all of whom reported steady temperature increases, particularly in Ethiopia's lowland pastoral regions.

The Rayitu temperature trends also support existing evidence linking climate warming to growing livelihood challenges. Comparable studies by Dejene et al. (2023) and Gebbisa & Bacsi (2025) documented a continuing rise in night-time temperature across southern rangelands, increasing livestock heat stress and water demand while reducing grazing efficiency. Similarly, Sintayehu et al. (2025) observed that higher minimum temperatures alter the thermal balance of livestock and restrict natural cooling, particularly during the dry season.

The correlation analysis between rainfall and temperature shows a mixed but seasonally contrasting relationship (Table 5): spring rainfall is strongly and negatively correlated with all temperature indices ($r \approx -0.495$; $p < 0.01$), indicating that higher temperatures suppress rainfall during the main rainy season that regenerates pasture and water. In contrast, rainfall–temperature relationships in other seasons are weak or non-significant. This reinforces Alemayehu et al. (2024) and Kourouma et al. (2022), who found similar inverse associations in southern

Ethiopia, showing that warming increases evapotranspiration and atmospheric dryness during the Belg period. The negative link between rising temperature and spring rainfall, therefore, supports Hypothesis H2, albeit partially, as the effect is season-specific rather than uniform year-round.

Table 5: Correlation between rainfall and temperature (1980-2024)

	Temperature						Rainfall	
Season	Max Temp	P-Value	Min Temp	P-Value	Mean Temp	P-Value	Mean	SD
Winter rainfall	-0.256	0.090	-0.086	0.576	-0.210	0.167	17.87	22.68
Spring rainfall	-.495**	0.001	-.326*	0.029	-.443**	0.002	218.1	72.22
Summer rainfall	0.024	0.875	0.061	0.689	0.067	0.662	12.64	9.22
Autumn rainfall	0.036	0.815	0.146	0.339	0.088	0.563	149.7	87.72
Annual rainfall	-.318*	0.033	-0.101	0.510	-0.236	0.119	398.3	120.2

Source: Authors own computation using XLStata Version 2025. ** and * represents significant level at 1% and 5% level respectively

3.2.2 Drought

The study assessed drought severity and frequency in Rayitu district using the Precipitation Concentration Index (PCI), Standardized Precipitation Index (SPI), and Standardized Precipitation Evapotranspiration Index (SPEI). Together, these indices provided a comprehensive understanding of rainfall concentration, drought occurrence, and climate-driven water stress in the study area.

The precipitation concentration index (PCI), results indicate that rainfall distribution in Rayitu district is highly irregular and concentrated within a few months of the year. As indicated on table 6, more than 84.45% of the years fell within the strongly irregular category (PCI > 20), while no year showed uniform rainfall distribution. The increasing PCI trend further suggests rising rainfall concentration and variability over time, consistent with findings from Borana, Afar, and other pastoral regions of Ethiopia (Ayugi et al., 2021; Duba, 2022; Worku, 2024). Such rainfall concentrations increase runoff, erosion, prolonged dry periods, and drought vulnerability while reducing the reliability of rain-fed pastoral and agropastoral systems.

Table 6: Frequency of precipitation concentration index (1980-2024)

SN	Classification	Name	Occurrence	Frequency
1	<10	Uniform	0	0
2	11-15	Moderates	0	0
3	16-20	Irregular	7	15.55
4	>20	Strongly irregular	38	84.45
		Total	45	100.00

Source: Authors own computation from DrinC software, based on classification of Olive (1980)

From a practical perspective, the results of table 6 suggest that precipitation in the study area is overwhelmingly irregular in terms of its distribution throughout the year. This is because 84.45% of the total years (38 out of 45) fall into the "very irregular" category, while not a single year falls into the "uniform" or "moderate" categories. This means that rainfall does not follow a predictable and evenly distributed pattern within a season but is concentrated in the form of short, intense downpours, thereby increasing both the risk of localized flooding and runoff losses as well as the risk of long-term droughts between rainfall events. Both factors hinder the stable growth of pastures and the recharge of water sources.

The Standardized Precipitation Index (SPI) analysis confirmed recurrent drought conditions across multiple timescales in Rayitu district. SPI-3 indicated frequent short-term droughts causing immediate pasture and water shortages, while SPI-6 and SPI-12 reflected persistent seasonal and long-term moisture deficits affecting livestock production and household resilience. Table 7 shows that mild drought was the dominant category, particularly under SPI-12 (44.44%), whereas severe drought was more concentrated at the short seasonal scale (SPI-3 = 15.56%), and extreme drought remained relatively rare. The findings suggest persistent background dryness and recurrent water stress in the area, consistent with previous studies from Borana, Afar, and other Ethiopian pastoral lowlands (Tesfamariam et al., 2019; Dejene et al., 2023; Aytenfisu et al., 2024). SPI-3 was found useful for rapid drought response, while SPI-6 and SPI-12 are more suitable for seasonal and long-term drought monitoring.

Table 7: Frequency Distribution of SPI and SPEI Drought Categories (1980–2024)

Classification	Drought Category	SPI-12 (%)	SPI-6 (%)	SPI-3 (%)	SPEI-12 (%)	SPEI-6 (%)	SPEI-3 (%)
> 0	No	42.22	48.89	57.78	57.78	42.22	40.00
-0.01 to -0.99	Mild	44.44	37.78	24.44	35.56	46.67	48.89

-1.00 to -1.49	Moderate	8.89	6.67	2.22	2.22	8.89	8.89
-1.5 to -1.99	Severe	2.22	2.22	15.56	0.00	0.00	2.22
< -2.0	Extreme	2.22	4.44	0.00	4.44	2.22	0.00

Source: Author's own computation from DrinC software, based on classification of McKee et al. (1993).

In practical terms, the results of SPI in table 7 show that drought is not a rare event but a common and recurring part of the climate in the study area. This is because mild drought conditions occurred in the years across all three-time scales (44.44% for SPI-12, 37.78% for SPI-6, and 24.44% for SPI-3). Moderate to severe droughts occur more frequently on a 3-month scale (17.8%) than on a 6 and 12-month scale, suggesting that short-term, distinctly seasonal droughts, which most severely disrupt pasture regeneration and calf calving cycles, pose a more urgent operational risk than prolonged, multi-year droughts.

Similarly, the SPEI results described increasing drought stress when the effects of temperature-driven evapotranspiration were incorporated. SPEI-3 indicated recurrent seasonal droughts causing rapid declines in pasture and water availability, while SPEI-6 and SPEI-12 reflected prolonged multi-seasonal and annual drought conditions. As shown in table 7, mild drought was still the most common type, making up 48.89% of SPEI-3 and 46.67% of SPEI-6 observations. Although extreme drought events were relatively rare, the severe drought episodes observed during 2021–2022 caused substantial impacts on livestock, grazing resources, and household livelihoods. These findings align with studies from pastoral areas of Ethiopia and East Africa, which emphasize that increasing temperature and evapotranspiration intensify drought severity even during periods of relatively normal rainfall (Worku, 2024; Gatew & Guyo, 2024; Makula et al., 2025).

From an operational perspective, the results of SPEI in table 7 suggest that, while the severity of drought has been somewhat mitigated when rainfall and evapotranspiration are considered comprehensively, a significant drought burden still exists. Drought occurred in 42.22–60% of the years across various scales, and mild droughts still occur frequently (35.6–48.9%). The fact that drought signals persist even after accounting for evapotranspiration confirms that water stress in this livestock system is driven by both insufficient precipitation and increased water demand due to rising temperatures, which is consistent with the previously identified warming trend (Table 4).

The quantitative findings were further supported by focus group discussions and key informant interviews. Participants consistently reported that droughts have become more frequent, longer lasting, and more destructive than in the past. Communities identified livestock mortality, declining milk production, recurrent crop failure, migration, and increasing livelihood insecurity as the major consequences of recent drought events.

3.2.3 Households' perception of climate change

3.2.3.1 Indicators of household perception of climate change

In this study, household perceptions of climate change were assessed using direct climate variability and indirect indicators of environmental and livelihood impacts, with significant correlations being confirmed by chi-square tests. As shown in Table 8, most pastoral households (78.9%) recognized clear signs of climate change, while 21.1% were unaware of its occurrence. This level of awareness was also evident across the specific indicator categories. On average, 79% of pastoralist households identified indirect indicators of climate change, whereas a slightly lower proportion (75%) recognized direct indicators. Conversely, 21% and 25% of households were unaware of indirect and direct indicators of climate change, respectively.

Table 8: Pastoralist perception of indicators of climate change

SN	Climate change indicators	Respondent/household perception		X^2 test
		Yes (%)	No (%)	
I	Direct Indicators	75%	25%	
1	Change in temperature seasonal pattern	257 (73.2%)	94(26.8%)	0.013
2	An extended period of high temperature	217 (61.8%)	134 (38.2 %)	0.006
3	Decreased frequency of rainfall	316(90.3%)	34(9.7%)	0.014
4	Irregular distribution of rainfall	217(61.8%)	134(38.2%)	0.007
5	Increase in wind frequency over time	275(78.3%)	76(21.7 %)	0.002
6	Drought	297 (84.6 %)	54 (15.4 %)	<0.001
II	Indirect indicators	79%	21%	
7	Drying up of grazing land	321 (91.5 %)	30 (8.5 %)	<0.001
8	Reduction in the water source	244(69.5 %)	107 (30.5 %)	0.003
9	Death of livestock	302 (86%)	49 (14%)	<0.001
10	Decline of crop production	248 (70.7%)	103 (29.3%)	<0.001
11	Poor livestock productivity	292 (83.2 %)	59 (16.8%)	<0.001

SN	Climate change indicators	Respondent/household perception		X^2 test
		Yes (%)	No (%)	
12	Loss of pastureland	256 (72.9%)	95 (27.1%)	0.002
	Overall (Direct +Indirect)	78.9%	21.1%	

Source: Author's own computation using SPSS Version 29

As Table 8 indicated direct indicators revealed that 73.2% of households perceived noticeable changes in seasonal temperature patterns, while 84.6% reported that droughts occur repeatedly every few years rather than once in several decades. Similarly, 90.3% of respondents observed declining rainfall frequency, and 61.8% reported increasingly irregular rainfall distribution, resulting in shortened growing seasons and reduced pasture regeneration. These findings are consistent with studies from Ethiopia and Kenya, where rising temperatures and erratic rainfall patterns have disrupted traditional pastoral and livestock production systems (Opiyo et al., 2016; Abrham & Mekuyi, 2022). In addition, 78.3% of households perceived increasing wind intensity, which contributes to soil erosion and rangeland degradation, supporting observations from the Turkana pastoral region of Kenya (Opiyo et al., 2016).

The indirect indicators presented in Table 8 further confirm the severity of climate-related impacts on pastoral livelihoods. The drying of grazing land (91.5%) and declining pasture availability (72.9%) were identified as the most severe challenges affecting pastoral livelihoods. These environmental stresses have contributed to reduced livestock productivity (83.2%), increased livestock mortality (86%), and declining crop production (70.7%). Furthermore, reduced water availability (69.5%) has forced pastoral households, particularly women and children, to travel longer distances in search of water, thereby increasing labor burdens and household stress. Similar findings were reported by Tesfahunegn et al. (2016) and Abrham and Mekuyi (2022). Respondents also highlighted the disappearance of traditional water sources, drying ponds, and the declining reliability of indigenous weather forecasting systems, indicating that changing climatic conditions are increasingly undermining local ecological knowledge. Perceptions varied across demographic groups, with women emphasizing the growing burden of water and resource scarcity, while older pastoralists relied more heavily on accumulated indigenous experience to interpret climatic changes, consistent with findings by Saguye (2017) and Nyamai et al. (2024).

Evidence from focus group discussions and key informant interviews further supported these findings. Most households clearly perceive climate change over

time, although they sometimes avoid using the term "climate change," instead explaining it as rainfall has become more erratic, rainy seasons start later and end earlier, and droughts have become more frequent and prolonged. Households associated these changes with declining pasture availability, drying water sources, reduced milk production, livestock disease outbreaks, and repeated crop failure. Elders emphasized that traditional seasonal forecasting systems are becoming unreliable, while women highlighted the increasing burden of collecting water and fuelwood. Similar observations have been documented by Debela et al. (2015), Habte Mariam et al. (2016).

3.2.3.2 Determinants of household perception

Table 9 shows the mean coefficients, which represent the average magnitude of influence of the individual explanatory variables within each category. Among the determinant factors, an environmental factor (average $\beta = 1.2585$) had the greatest positive impact on households' perceptions of climate change, followed by economic factors (average $\beta = 0.8354$), institutional factors (average $\beta = 0.6915$), and socio-demographic factors (mean $\beta = 0.4465$). This suggests that, on average, variables related to direct environmental changes have the greatest influence on shaping pastoralists' perceptions, whereas socioeconomic characteristics make a relatively smaller contribution. The binary logistic model output of the individual determinants of pastoral households' perception is indicated in table 9.

Table 9: Determinants of household perception by binary logistic regression

SN	Variables	B	S.E.	Wald	Sig.	Exp(B)
I	Socio-demographic factors					
1	Sex of the household	-0.451	0.409	1.216	0.270	0.637
2	Family size	0.570	0.247	5.308	0.021	1.768
3	level of Education	-0.598	0.141	17.949	0.000	0.550
4	Age of the households	0.167	0.074	5.146	0.023	1.182
	Mean	0.446		7.405	0.75	
II	Economic factors					
5	Access to savings	0.613	0.320	3.675	0.055	1.845
6	Size of pastureland (ha)	0.456	0.202	5.090	0.024	1.578
7	Crop production	0.786	0.342	5.271	0.022	2.195
8	livestock holding	1.555	0.435	12.760	0.000	4.735
9	Livelihood diversification	-0.767	0.401	3.665	0.056	0.464
	Mean	0.835		6.092	1.00	

SN	Variables	B	S.E.	Wald	Sig.	Exp(B)
III	Institutional factors					
10	Access to a health facility	0.932	0.334	7.776	0.005	2.540
11	Membership of the cooperative	-0.494	0.354	1.950	0.163	0.610
12	Access to weather information	-0.574	0.438	1.717	0.190	0.563
13	Access to extension service	-0.766	0.348	4.852	0.028	0.465
	Mean	0.691		4.073	0.50	
IV	Environmental & physical factors					
14	Grazing land condition	2.170	0.647	11.256	0.001	8.756
15	Distance of weekly market (km)	-0.347	0.201	2.981	0.084	0.707
	Mean	1.259		7.119	0.50	
	Constant	-8.549	1.994	18.378	0.000	0.000

Source: Author's own computation using SPSS Version 2

Among socio-demographic variables, family size and age positively and significantly affected climate perception, implying that larger and older households are more likely to recognize environmental changes due to greater livelihood exposure and accumulated indigenous knowledge. This finding is in line with the work of Debela et al., 2015; Tesfahunegn et al., 2016; Saguye, 2017; Maziya and Nkonki-Mandleni, 2024; Nyamai et al., 2024. In contrast, education exhibited a significant negative relationship, indicating that households involved in non-pastoral activities may experience less direct exposure to climate risks. This is consistent with Alotaibi et al. (2023).

Economic factors emerged as robust predictors of perception, as shown in Table 9. Households with larger pastureland size, engagement in crop production, and greater livestock holdings had strong positive effects, with livestock ownership emerging as the strongest predictor of climate perception. This finding reflects the high dependence of pastoral households on climate-sensitive livestock systems, consistent with findings by Opiyo et al. (2015) and Idrissou et al. (2021). Access to savings also enhanced awareness, as financial security facilitates access to information and adaptive measures, consistent with Pienaah and Luginaah (2024). Conversely, livelihood diversification had a weak negative association, indicating that households less dependent on climate-sensitive activities tend to be less observant of climatic shifts, supporting similar conclusions by Nyamai et al. (2024).

Institutional factors in Table 9 presented a mixed effect. Access to health facilities had a significantly positive effect, underscoring the role of local service centers as conduits for information about climate-related health and environmental risks (Tesfahunegn et al., 2016; Idrissou et al., 2021). However, veterinary extension services were negatively associated with perception, possibly because such services focus narrowly on disease management rather than linking animal health to climatic factors. This finding aligns with Opiyo et al. (2015) and Saguye (2017). Membership of cooperatives and access to weather information both showed statistically insignificant but negative effects. This finding is consistent with the study of Maziya and Nkonki-Mandleni (2024) and suggests that institutional structures may not effectively support climate change adaptation.

Among environmental and physical variables, the condition of grazing land was the most influential predictor. Households observing pasture degradation and declining rangeland health were almost nine times more likely to perceive climate change. This finding is strongly supported by Debela et al. (2015), Mekuyi and Mulu (2021), and Abrham and Mekuyi (2022), who reported that ecological deterioration and fodder scarcity are key triggers of climate perception among pastoralists. Distance from weekly markets had a weak negative association, likely due to reduced opportunities for social learning and exchange of environmental information (Saguye, 2017).

Diagnostic tests confirmed the robustness of the logistic regression model. The Omnibus test was statistically significant (LR $\chi^2 = 139.559$, $p < 0.001$), while the Hosmer–Lemeshow test indicated excellent model fit ($p = 0.32$). The pseudo-R^2 values further showed moderate explanatory power.

3.2.4 Household vulnerability

3.2.4.1 Measuring household vulnerability

This study applies principal component analysis (PCA) to measured household vulnerability level. The suitability of the data for PCA was assessed using the Kaiser-Meyer-Olkin (KMO) and Bartlett's Test of Sphericity. The KMO value of 0.706 indicates acceptable sampling adequacy according to Kaiser (1974), suggesting that the variables share sufficient common variance for factor analysis. In addition, Bartlett's Test of Sphericity was highly significant ($\chi^2 = 1794.917$, df = 406, $p < 0.001$), rejecting the null hypothesis that the correlation matrix is an identity matrix. These results confirm that the dataset is appropriate for PCA and

that the extracted components provide reliable and interpretable measures of household vulnerability.

This study groups variables into five types of livelihood capital, such as human, financial, social, natural, and physical, which are combined into a single composite dimension to measure the contribution of livelihood capital to household vulnerability, as indicated in table 10.

Table 10: Contribution of livelihood capital assets to household vulnerability

SN	Component Matrix	Component	Square of components	Contribution %
I	Human Capital asset		0.751	12.34
1	Education level of HHs	0.032	0.001	0.02
2	Training participation of HHs	-0.573	0.328	5.4
3	Health status of households	0.301	0.091	1.49
4	Livelihood experience of HHs	0.575	0.331	5.43
II	Financial Capital Assets		0.937	15.39
5	Total income	0.379	0.144	2.36
6	Total expenditure	0.492	0.242	3.98
7	Access to savings	-0.056	0.003	0.05
8	Access to credit	-0.447	0.2	3.28
9	Received remittance	-0.355	0.126	2.07
10	Access to an insurance	-0.263	0.069	1.14
11	Tropical Livestock Unit	-0.391	0.153	2.51
III	Social Capital Assets		0.455	7.48
12	Members of cooperative	-0.622	0.387	6.36
13	Access to information	-0.164	0.027	0.44
14	Access to extension service	-0.203	0.041	0.68
IV	Natural Capital		0.022	0.36
15	Rangeland (Ha)	-0.146	0.021	0.35
16	Farmland (Ha)	0.029	0.001	0.01
V	Physical Capital		3.92	64.43
17	Access to potable water	0.664	0.441	7.25
18	Access to livestock water	0.802	0.643	10.57
19	Distance to road (km)	-0.04	0.00016	0.02
20	Distance to market (km)	0.61	0.372	6.12
21	Access to electricity	-0.526	0.277	4.55

SN	Component Matrix	Component	Square of components	Contribution %
22	Distance to school (km)	0.067	0.004	0.07
23	Distance to health center (km)	0.888	0.789	12.96
24	Distance to pastoral training (km)	0.81	0.656	10.78
25	Distance to health post (km)	0.859	0.738	12.13

Source: Author's own computation using Stata Version 17

Table 10 indicated that physical capital has emerged as a key determinant of vulnerability, accounting for 64.43% of the total explained variance, a figure more than four times that of the next largest category, financial capital (15.39%). The variables with the highest load were distance to health centres (12.96%), veterinary posts (12.13%), pastoral training centres (10.78%), and livestock water access (10.57%). Access to electricity, on the other hand, had a load in the opposite direction. These results suggest that vulnerability in the study area stems primarily from spatial and infrastructural remoteness rather than asset ownership. In other words, poor physical access to services, markets, and support networks is severely hindering pastoralist households' ability to cope with and recover from climate-related stresses. These findings are consistent with previous studies (Tofu et al., 2025; Gatew & Guyo, 2024; Yimam & Holvoet, 2023; Tasnuva et al., 2021; Uddin et al., 2019).

Financial capital accounted for 15.39% of the total variance, emerging as the second most influential sector after physical capital. Household expenditure (3.98%) and income (2.36%) showed the strongest positive loadings, while tropical livestock units (2.51%), credit access (3.28%), and remittances (2.07%) loaded negatively; savings (0.05%) and insurance (1.14%) contributed negligibly. This reflects an "income versus buffer strategy" dimension, distinguishing households with higher cash liquidity from those relying on alternative mechanisms such as credit, remittances, and livestock, suggesting that households with limited direct income depend more on informal coping strategies. The weak loading for savings further indicates that formal financial services play a limited differentiating role, likely reflecting accessibility constraints. These results align with recent studies (Asfaw et al., 2021b; Gatew & Guyo, 2024; Tasnuva et al., 2021; Tofu et al., 2025; Yimam & Holvoet, 2023; Uddin et al., 2019).

Human capital accounted for 12.34% of the total variance, indicating that it makes a moderate contribution to vulnerability. Livelihood experience (5.43%) and

participation in training (5.40%) were the key indicators; the opposing loads of these two indicators distinguished between households that rely on experiential knowledge and those that benefit from formal technical training. Educational level (0.02%) and health status (1.49%) made relatively small contributions, suggesting that practical experience and skill development are more important for vulnerability in this study area than formal education or health status (Gatew & Guyo, 2024; Tofu et al., 2023; Yimam & Holvoet, 2023).

Social capital explained 7.48% of the total variance, the second-lowest contribution among the five domains. Cooperative membership dominated this domain (6.36%), accounting for roughly 85% of its explanatory contribution, likely reflecting access to pooled resources, collective bargaining, and mutual risk-sharing. Access to weather information (0.44%) and veterinary extension services (0.68%) contributed only marginally, indicating limited association with household vulnerability in pastoral areas (Gatew & Guyo, 2024; Opiyo et al., 2014).

Natural capital made the smallest contribution to vulnerability (0.36%), comprising mainly rangeland (0.35%) and agricultural land (0.01%). This limited contribution suggests that household size and land ownership explain little of the variation in vulnerability, while land quality, tenure security, fragmentation, and access to communal resources may be more important. Therefore, broader indicators of natural capital are needed in pastoral and agro-pastoral contexts, as communal rangeland access may improve feed availability and herd-management flexibility without necessarily reducing vulnerability (Gatew & Guyo, 2024; Molla et al., 2024; Tofu et al., 2025).

From a practical perspective, the finding in Table 10 shows that physical capital is by far the most important factor in household vulnerability (64.43% contribution). This is especially true for distance to health centres, pastoral training centres, and veterinary posts, as well as access to potable and livestock water. This means that vulnerability in this pastoral area is mostly a problem with infrastructure and service access, not a problem with resource endowment. Financial capital (15.39%) and human capital (12.34%) contribute moderately, while social capital (7.48%) and especially natural capital (0.36%) contribute minimally, suggesting that land availability alone does little to explain vulnerability compared to access to services and markets.

3.2.4.2 Determinants of household vulnerability

An ordinal logistic regression model was employed to identify the determinants of household vulnerability across the five livelihood capitals. The model performed well statistically, with an LR chi-square value of 163.21 ($p < 0.001$) and a pseudo-R^2 of 0.5215, indicating strong explanatory power.

Household vulnerability to livelihood shocks arises not from any single factor but from the interaction of the various forms of capital available to households. Drawing on the sustainable livelihood's framework (Scoones, 1998; DFID, 1999), this section examines the marginal effect of human, financial, social, natural, and physical capital on the likelihood that households experience low, medium, or high vulnerability as indicated in table 11.

Table 11: Marginal effects of determinants of household vulnerability

Variable	Low Vulnerability		Moderate Vulnerability		High Vulnerability	
	dy/dx	P>|z|	dy/dx	P>|z|	dy/dx	P>|z|
Human capital						
Education (years)	0.0098	0.019	-0.0018	0.033	-0.0081	0.020
Training received	0.1070	0.001	-0.0191	0.012	-0.0879	0.001
livelihood experience	-0.0107	0.000	0.0019	0.000	0.0088	0.000
Health status	-0.3117	0.000	0.0556	0.000	0.2561	0.000
Financial Capital						
Access to savings	0.0501	0.108	-0.0089	0.118	-0.0412	0.109
Access to credit	0.0980	0.005	-0.0175	0.017	-0.0806	0.005
Remittance receipt	0.1294	0.000	-0.0231	0.002	-0.1063	0.000
Insurance access	0.1199	0.011	-0.0214	0.019	-0.0985	0.012
Livestock _(TLU)	-0.0107	0.059	0.0019	0.067	0.0088	0.062
Social Capital						
Member. of cooperative	0.0714	0.034	-0.0127	0.062	-0.0587	0.032
Weather information	0.0842	0.028	-0.0150	0.051	-0.0692	0.027
Vet. extension access	0.0599	0.071	-0.0107	0.072	-0.0492	0.075
Natural Capital						
Rangeland size (ha)	-0.0243	0.123	0.0043	0.154	0.0200	0.120

Variable	Low Vulnerability		Moderate Vulnerability		High Vulnerability	
	dy/dx	P>|z|	dy/dx	P>|z|	dy/dx	P>|z|
Farm size (ha)	0.0041	0.754	-0.0007	0.758	-0.0033	0.754
Physical Capital						
Potable water access	-0.0129	0.263	0.0023	0.246	0.0106	0.269
Livestock water access	0.0191	0.082	-0.0034	0.079	-0.0157	0.087
Distance to road (km)	-0.0357	0.000	0.0064	0.001	0.0293	0.000
Distance to market (km)	-0.0048	0.532	0.0009	0.533	0.0040	0.532
Electricity access	-0.0316	0.630	0.0056	0.641	0.0260	0.628
Distance H/center (km)	-0.0044	0.213	0.0008	0.229	0.0036	0.213
Distance to PTC (km)	-0.0337	0.000	0.0060	0.000	0.0277	0.000

Source: Author's own computation using Stata Version 17

Human capital is a key determinant of vulnerability to climate change, and health, education, and training serve as major protective factors. While health has the greatest impact, training and education significantly reduce the likelihood of high vulnerability. These findings support the view that education, practical training, and optimal health strengthen households' capacity to prepare for, adapt to, and cope with climate shocks (Wingfield et al., 2020; Fenta et al., 2019; Zeleke et al., 2021; Snaibi et al., 2021; Lankamo et al., 2025). Conversely, it was found that the greater the diversity of livelihood experience, the higher the vulnerability; this finding is likely because continued reliance on traditional practices may limit the adoption of new adaptation strategies (Taruvinga et al., 2016).

Financial capital is one of determinant of the vulnerability of households in pastoralist systems and provides a buffer against shocks to livelihoods. Credit, remittances, and insurance significantly reduce the likelihood of being highly exposed by around 8.1, 10.6, and 9.9 percent, respectively, while saving has negative but statistically insignificant effects. These findings confirm the importance of external financing for climate resilience, in line with the conclusions of Dejene (2020), Opiyo et al. (2014), and Zeleke (2021). On the other hand, larger livestock holdings are positively correlated with vulnerability, indicating that herd size alone does not guarantee resilience and may increase exposure to feed and water shortages. Thus, productivity and the resilience of the livestock are more important than the size of the herd itself.

Social capital plays an important protective role in reducing pastoral household vulnerability by improving access to information, collective action, and support services. Cooperative membership and access to climate information significantly reduce the probability of high vulnerability by approximately 5.9 and 6.9 percent, respectively. Veterinary extension services also reduce vulnerability, although the effect is only marginally significant ($p = 0.072$). Overall, strengthening social networks, timely climate information, collective action, and extension services can enhance households' adaptive capacity and resilience, consistent with previous studies (Opiyo et al., 2014; Addis et al., 2021; Zeleke et al., 2021).

Natural capital shapes the way pastoral households interact with land and thus affects their exposure to climate shocks and livelihoods. The study considers natural capital in terms of grazing areas and farmland. The findings show that neither rangeland size nor farm size attained statistical significance. This suggests that land quantity, in isolation, is a weak predictor of vulnerability, a pattern consistent with arguments that land quality, degradation, and tenure security rather than sheer size determine natural capital's protective value (Behnke & Kerven, 2013).

Physical capital is an important determinant of pastoral household vulnerability, particularly through geographical accessibility. Greater distance from roads and pastoral training centres (PTCs) significantly increases the probability of high vulnerability by approximately 2.9 and 2.8 percent per additional kilometre, respectively. This remoteness limits access to markets, public services, information, and emergency assistance, making it more vulnerable to livelihood shocks. This observation is in line with the findings of Ghosh and Ghosal (2020).

In practical terms, Table 19 shows that infrastructural remoteness and limited financial buffering, rather than land-based assets, primarily drive vulnerability. Policy should prioritize improving access to services (health, veterinary, training, water), expanding financial tools (credit, remittances, insurance), and strengthening cooperative networks. Training and education are effective household-level levers, while reliance on traditional experience alone may hinder adaptation. Land-based natural capital plays a limited role, confirming that vulnerability stems more from structural access constraints than asset ownership, pointing to the need for integrated interventions across infrastructure, finance, and human capital.

3.2.5 Determinants of coping and adaptation strategies

Qualitative findings from focus group discussions and key informant interviews identified common coping mechanisms (destocking, PSNP participation, casual labour, and reduced food intake) and adaptation strategies (livestock migration, drought-tolerant breeds, herd diversification, non-farm diversification, and soil and water conservation) used by pastoral households. These strategies were incorporated as dependent variables in a multivariate probit model, which showed that human, financial, social, natural, and physical capital significantly influence households' coping and adaptation choices, as indicated in table 12.

Before running the regression/marginal effects model, the study checked the diagnostic test of multicollinearity, and the result confirmed that there is no serious multicollinearity among the independent variables: the mean VIF (1.26) is well below the threshold of 5, and all pairwise correlations are below 0.80. This satisfies the assumption of independence among explanatory variables, so all variables can be safely retained in the model. Finally, the result of the model is discussed as follows:

Human capitals

This study represents human capital through education, training, health status, and livelihood experience. It shapes both how pastoral households cope with immediate shocks and how they adapt over the longer term, primarily by strengthening knowledge, decision-making capacity, and access to information (Silvestri et al., 2012).

In terms of coping, education significantly increases the likelihood of destocking, short-term casual labour, and reduced daily food intake by 5.3%, 5.5%, and 3.2%, respectively. This suggests that more educated households can deliberately adjust consumption and labour allocation as planned responses rather than purely distress-driven reactions (Alemayehu & Bewket, 2017; Gebre et al., 2021; Megersa et al., 2022; Silvestri et al., 2012). Training's coping role is narrower, significantly reducing food intake by only 3.35 per cent. It is consistent with trained households prioritising the protection of productive assets over consumption adjustments (Silvestri et al., 2012). Health status and livelihood experience show no significant coping effects, indicating that once education and wealth are accounted for, access to resources matters more than personal health or tenure in shaping coping choices.

Table 12: Marginal effect (dy/dx) of determinants of household coping and adaptation strategies

Variable	Coping Strategies				Adaptation strategies				
	DS	PSP	SCL	RDFI	SLM	DTL	HD	NFD	SWC
Human Capital									
Education level of HHs	.0527***	0.014	0.055***	.0317***	0.0095*	0.0074	-0.004	-0.0065	-0.0099
Training of HHs	0.0178	- 0.005	0.0013	.0335**	-0.0325	0.0287	0.0045	-0.0255	-0.0157
Health status of HHs	-.0898*	-0.015	-0.046	0.0288	0.0585	-0.0271	0.0009	-0.033	-0.0588
Livelihood experience	-0.0012	0.005**	-0.002	-0.0014	0.0053**	0.0023	0.0015	-0.003	0.005**
Financial capital									
Access to savings	-0.0203	0.091*	-0.078	-.0699**	-0.0706	-0.0288	0.0968**	0.133***	0.0679
Access to credit	-0.0441	0.139***	0.119**	-0.0127	-0.0107	-0.0728	0.0619	0.0187	-0.0354
Access to an insurance	0.0504	0.064	0.101	-0.0422	-0.0039	-0.0977	-0.0233	0.1256	0.0351
Tropical Livestock Unit	0.2246***	-0.020	-0.127*	0.0151	0.3168***	0.2181***	-0.143**	-0.026	-0.0444
Social capital									
Members of cooperative	-0.1152	0.058	-0.011	-0.0048	-0.0747*	0.0204	0.1182***	-0.0406	0.0354
Access to information	-0.0178	0.030	0.025	-0.0128	0.0375	-0.1185**	0.0409	-0.0133	-0.0018
Acc. to extension service	0.0482	0.019	-0.053	0.0366	-0.0144	-0.0154	0.1155**	0.1058**	-0.0688
Natural capital									
Rangeland (Ha)	.0706**	0.006	-0.078***	-0.0172	0.076***	0.0733**	-0.0126	-0.0081	0.0052
Farmland (Ha)	.0395**	0.008	0.034	-0.0182	0.0276	0.0318	0.0389*	0.0327*	-0.043**
Physical capital									
Access to potable water	-0.0081	-0.003	-0.006	-.0134***	-0.0138*	0.0197**	0.0039	0.0178**	-0.0184*
Distance to market (km)	-0.0137	0.019	-0.023	-.0388***	-0.0001	-0.0004	-0.0001	-0.0019***	0.0016***
Access to electricity	-.257***	-0.018	-0.086	-.1442***	-0.041	-0.239***	-0.0687	0.1172**	-0.0648
Distance to health center	0.0091	- 0.017***	0.012**	0.0015	0.0085	0.0099	-0.0032	0.0222***	0.0032

Source: Authors' own computation using Stata version 17. ***, ** and * represents significance at 1%, 5% and 10% level, respectively. **DS:** De-stocking, **PSP:** Productive Safety Net Program, **SCL**: Short-term casual labour, **RDFI**: reduction in daily food intake, **SLM:** Seasonal livestock migration, **DTL:** adoption of drought-tolerant livestock, **HD**: Herd diversification, **NFD**: Nonfarm diversification, **SWC**: Soil and water conservation.

In adaptation, the pattern shifts and education has a significant positive effect on seasonal livestock migration by 0.95 percent, reflecting improved capacity to process climate and market information (Berhanu & Beyene, 2015; Gebbisa & Bacsi, 2025). Training and health status show no significant adaptation effects, suggesting a limited translation of training exposure into behavioural change. Livelihood experience, by contrast, significantly increases adoption of both seasonal livestock migration and soil-and-water conservation by 0.52% and 0.53%, indicating that experience reinforces reliance on traditional, familiar strategies (mobility, conservation) rather than necessarily fostering innovation (Gebbisa & Bacsi, 2025; Regasa, 2025; Belay et al., 2017).

Therefore, in human capital's education and training act as protective, adaptive resources enabling deliberate and forward-looking responses. Livelihood experience, although positively associated with certain adaptive behaviours, primarily reinforces a continued reliance on traditional practices instead of fostering innovation, and its impact on reducing vulnerability may be influenced by other factors.

Financial capital

Financial capital, savings, credit, insurance, and livestock provide pastoral households a buffer against shocks, enabling consumption smoothing and protection of productive assets while avoiding distress coping (Abay et al., 2022; Feyissa et al., 2025).

For coping, savings significantly reduce reliance on cutting food intake by 6.99% and show a marginally positive association with PSNP participation, confirming its role as a consumption-smoothing buffer. Credit access strongly increases participation in both PSNP (13.9%) and short-term casual labour (12.0%), broadening households' coping options (Abay et al., 2022; Snaibi et al., 2021). Livestock holdings (TLU) significantly increase destocking (22.5%) while marginally reducing reliance on casual labour, indicating that livestock-wealthy households use herd adjustment as their primary coping lever rather than labour markets (Feyissa et al., 2025; Tilahun & Legese, 2020; Megersa et al., 2022; Sintayehu et al., 2025).

For adaptation, savings significantly raise the likelihood of both herd diversification (9.68%) and non-farm diversification (13.31%), reinforcing its role as a buffer enabling diversification rather than dependence on mobility alone (Letsoalo et al., 2023; Megersa et al., 2014; Yussuf & Mohamed, 2022). Credit

and insurance show no significant adaptation effects, suggesting limited penetration or a mismatch between these financial products and pastoral needs. Livestock holdings remain a dominant adaptation driver, strongly increasing seasonal migration (31.68%) and drought-tolerant livestock adoption (21.81%) while reducing herd diversification (14.35%), reflecting specialization among larger herd-owners (Berhanu & Beyene, 2015; Megersa et al., 2022; Regasa, 2025; Bedo et al., 2024).

The findings indicate that financial capital consistently functions as a risk-mitigating and diversification-enabling resource across both coping and adaptation, with savings and credit facilitating flexible, proactive responses, while livestock wealth anchors households toward mobility and herd-based strategies over diversification.

Social capital

In this study social capital incorporates the variables such as cooperative membership, information access, and extension services and shapes households' access to pooled resources and collective risk-sharing mechanisms (Ragasa, 2025; Opiyo et al., 2015). In coping, cooperative membership significantly reduces the probability of destocking (11.5%), suggesting that cooperatives provide alternative support (resource pooling, market information, and informal risk-sharing) that reduces the need for herd liquidation. Access to information and veterinary/extension services show no significant coping effects, pointing to possible gaps in targeting, service quality, or timeliness that prevent effective use of these channels during shocks.

In adaptation, cooperative membership significantly increases herd diversification (11.82%), consistent with cooperatives facilitating diversification through shared knowledge and pooled resources (Bedo et al., 2024). Access to information has a marginally significant negative effect on drought-tolerant livestock adoption (11.85%), possibly reflecting substitution toward other strategies such as mobility or diversification. Veterinary/extension access significantly supports both herd diversification (11.55%) and non-farm diversification (10.58%), confirming its role in building technical capacity for diversification (Feyera et al., 2017).

Therefore, the finding shows that social capital's protective value is concentrated in cooperative membership, which consistently supports both short-term coping (reducing destocking) and longer-term adaptation (enabling diversification), while weather information and extension access play a more limited or inconsistent role.

Natural capital

Natural capital in this study incorporates rangeland and farmland that define the resource base and opportunities for manoeuvre available to households (Letsoalo et al., 2023; Tsegaye et al., 2013). In coping, rangeland size has mixed effects: it significantly increases destocking (7.1%) while significantly reducing reliance on casual labour (7.8%), indicating that households with larger grazing areas favour livestock-based adjustments over labour markets. Farmland shows only a marginal positive effect on destocking, with no significant effect elsewhere, indicating a limited liquidity role (Alemayehu & Bewket, 2017; Zeleke et al., 2023).

In adaptation, rangeland significantly increases both seasonal migration (7.64%) and drought-tolerant livestock adoption (7.33%), confirming that grazing access strengthens livestock-based adaptive capacity (Gebbisa & Bacsi, 2025; Regasa, 2025; Wario et al., 2016). Farmland shows a broader adaptive role, positively affecting herd and non-farm diversification while negatively affecting soil-and-water conservation, consistent with larger landholdings reducing the perceived urgency of conservation investment (Gebrehiwot & van der Veen, 2013; Ndiritu, 2021).

The findings show that natural capital's influence operates mainly through livestock-based pathways (rangeland enabling mobility and destocking). Land-based diversification (farmland enabling non-farm and herd diversification), rather than through direct vulnerability reduction, reinforces that landholding size alone has limited explanatory power for vulnerability.

Physical capital

Physical capital variables included in this study are water, electricity, and proximity to markets, health centres, and services, which determine the relative cost and feasibility of both coping and adaptive responses (Degefu et al., 2019; Gebrehiwot & Hassen, 2022).

In coping, water access significantly reduces reliance on cutting food intake (1.3%), freeing time otherwise spent on water collection (Degefu et al., 2019; Ndiritu, 2021). Electricity access strongly reduces both destocking (25.7%) and food-intake reduction (14.4%), reflecting income diversification and reduced storage losses enabled by electrification (Gebrehiwot & Hassen, 2022). Proximity to health centres reduces PSNP participation, suggesting better-connected households are comparatively better-off and less safety-net-dependent (Abay et al., 2022).

In adaptation, water access reduces reliance on seasonal migration and soil-and-water conservation while promoting drought-tolerant livestock and non-farm diversification, again freeing households from mobility and conservation-based strategies (Degefu et al., 2019; Tofu et al., 2023). Distance to markets significantly discourages non-farm diversification while encouraging soil-and-water conservation, reflecting greater land dependence where market access is poor (Feyissa et al., 2025; Gashure & Wana, 2023; Berhanu et al., 2024). Electricity access reduces drought-tolerant livestock adoption while promoting non-farm diversification, indicating a shift from livestock-centred to infrastructure-enabled income strategies (Gebrehiwot & Hassen, 2022). Distance to health centres positively affects non-farm diversification, possibly reflecting fewer institutional mobility constraints or a need to offset the higher cost of accessing distant health services (Abate et al., 2020).

Therefore, the core finding is that physical capital operates as a double-edged determinant: proximity to infrastructure and services (water, electricity, health, markets) consistently reduces distress coping and expands non-farm and diversification-based adaptation, whereas remoteness compels continued reliance on land- and livestock-based, less flexible strategies, reinforcing physical capital's role as the dominant structural driver of both vulnerability and adaptive capacity.

From a practical perspective, the determinants of coping and adaptation strategies (Table 12) reveal complementary pathways that lead to resilience. Households with large herds are more likely to rely on reducing their livestock numbers when shocks occur, but they also adopt proactive strategies such as seasonal livestock migration and drought-resistant livestock breeds. Access to electricity, cooperatives, credit, and savings reduces reliance on coping strategies that deplete resources and promotes livelihood diversification. Similarly, the size of grazing lands and access to markets, health services, and other infrastructure influence both the intensity of coping and adaptation choices.

3.2 Result of Hypothesis testing

This section presents the results of hypothesis testing conducted in this study. A total of eight hypotheses were formulated based on the proposed conceptual framework to examine the relationships among the variables. Each hypothesis was tested using the appropriate statistical technique. Among the eight proposed hypotheses, four were accepted, two were partially accepted, and two were rejected, based on the model output.

Hypothesis 1: The monthly precipitation varies by seasons without an annual precipitation trend

H1 is accepted. As indicated in table 3, most months (January, February, March, June, July, August, September, and December) have a coefficient of variation (CV) above 100, indicating that rainfall is highly unreliable, while only April (CV = 38.2) and May (CV = 54.5) are relatively stable. Seasonally, there is high variability in winter (CV = 126.9), autumn shows relatively low variability (CV = 58.6), and spring is relatively stable (CV = 33.3). The Mann-Kendall test does not show any significant long-term trend in annual precipitation (τ = -0.046, slope = -0.463, p = 0.660). Therefore, these results support the theory of non-equilibrium ecology (Ellis & Swift, 1988), which states that in arid rangeland systems, high precipitation variability (CV > 30%) rather than biological processes drives resource dynamics.

Hypothesis 2: Annual and seasonal temperatures show a positive trend and temperatures are negatively correlated to precipitation

H2 is partially accepted. The Mann-Kendall results (Table 4) show a clear and statistically significant warming trend in the monthly, seasonal, and annual mean temperature. Most minimum, maximum, and average mean temperatures show positive and significant trends, with a mean slope of approximately between 0.03 and 0.034 degrees Celsius per year, confirming a strong warming signal in the Rayitu districts. However, the relationship between temperature and rainfall is mixed (Table 5): the correlation between winter and summer is weak and negligible, while spring (Belg) rainfall has a strong and significant negative correlation with all temperature indices, which means that warmer conditions reduce rainfall in the main wet season. Autumn shows a slight, non-significant positive correlation, and annual precipitation is only significantly negatively correlated to maximum mean temperature. Therefore, the warming trend is well supported, but the expected negative relationship between precipitation and temperature is mainly true for spring and annual precipitation in relation to maximum average temperature.

Hypothesis 3: Annual precipitation is concentrated in specific months, and the occurrence of mild drought is dominant

H3 is accepted and supported. As shown in Table 6, approximately 84.45% of the recorded years showed highly irregular precipitation (PCI > 20), while 15.55% showed a uniform precipitation distribution (PCI $\leq$ 20). Similarly, as tables 7

indicated, the drought patterns range from mild to extreme across the 3-month, 6-month, and 12-month SPI and SPEI scales; the mild drought is dominant at all scales. Therefore, the Rayitu district experiences highly variable precipitation, with recurring episodes of primarily mild drought interspersed with moderate, severe, and extreme droughts that pose significant risks to pastoralists' livelihoods and climate risk management.

Hypothesis H4 - A higher proportion of pastoral households perceive direct (meteorological) climate impacts than indirect (livelihood-related) climate change indicators.

H4 is rejected. As indicated in table 8, pastoral households perceive climate change more strongly through its livelihood consequences than through direct meteorological cues. Because indirect/livelihood indicators (mean = 79.0%) were perceived at significantly higher rates than direct/meteorological indicators (mean = 75.0%), $\chi^2 = 9.45$, $p < 0.01$). This finding aligns with the availability heuristic (Tversky & Kahneman, 1973) and Protection Motivation Theory (Rogers, 1975) and states that households perceive climate change more strongly through visible and economically consequential livelihood losses, such as livestock deaths, pasture degradation, and crop losses, than through abstract changes in climatic conditions.

Hypothesis H5 - Economic and environmental/physical capital endowments have stronger magnitude effects on household perception than socio-demographic and institutional factors.

This hypothesis is accepted. The supportive evidence shown in table 9 is that economic and environmental/physical capital endowments generate a larger magnitude of change in household climate perception ((4.177+2.517)/5+2=0.956) compared to the change in household climate perception caused by socio-demographic and institutional factors ((1.786+2.766)/4+4=0.569) in shaping perceptions. The acceptance of this hypothesis is theoretically substantiated by the convergence of perspectives from the Asset Vulnerability Framework (Moser, 1998), experience-based risk processing (Webers, 2006), the availability heuristic (Tversky & Kahneman, 1973), prospect theory (Kahneman & Tversky, 1979), and protection motivation theory (Rogers, 1975). These frameworks suggest that tangible economic and environmental losses are more directly experienced, vivid, and consequential than socio-demographic or institutional conditions.

Consequently, such losses generate stronger perceptions of vulnerability and risk responses, explaining their larger effect magnitudes and supporting H5.

Hypothesis H6 - The combined effects of human and financial capital are expected to have a stronger influence on household vulnerability than natural and physical capital.

H6 is rejected. The results in table 10 show that natural and physical capital account for 64.79% (0.36% + 64.43%) of the explained variance, while human and financial capital account for 27.73% (12.34% + 15.39%). Therefore, the contribution of natural and physical capital is 37.06 percentage points higher, and the contribution ratio is approximately 2.3:1 (Table 18). This significant difference is consistent with the asset-vulnerability framework (Moser, 1998; Chambers & Conway, 1992) and the sustainable livelihoods approach (Scoones, 1998; DFID, 1999), which emphasize that physical and natural assets provide the essential conditions that enable human and financial capital to effectively reduce household vulnerability.

Hypothesis H7 - Higher human capital endowments (education, training, livelihood experience, health status) reduces the probability of high vulnerability of pastoral households.

H7 is partially accepted. Formal education and technical training reduce the likelihood of high vulnerability among nomadic households (Table 11) and are consistent with human capital theory (Becker, 1964; Schultz, 1961). However, experience in livelihood activities is associated with an increase rather than a decrease in vulnerability, suggesting that not all dimensions of human capital consistently function as protective assets in this context (Table 11).

Hypothesis H8 - Human, social, financial, natural, and physical capital have significantly different effects on pastoral households' coping and adaptation strategies.

H8 is accepted. Table 12 indicated the magnitude and direction of impacts vary across asset-related strategies and indicators. Results from the multivariate probit model provide strong support for this. For coping strategies, variables covering all five areas of capital are statistically significant in at least one of the four coping equations (destocking, participation in the PSNP, short-term casual work, and reduction of daily food intake). Similarly, adaptation strategies, indicators of human, social, financial, natural, and physical capital, have a significant impact on at least one of the five adaptation options (seasonal livestock migration,

adoption of drought-tolerant livestock, herd diversification, non-crop diversification, and soil and water protection).

Table 13: Summary of hypothesis evaluation

Hypothesis	Supportive evidence of model output (Table)	Decision
H1	3	Accepted
H2	4,5	Partially accepted
H3	6,7	Accepted
H4	8	Rejected
H5	9	Accepted
H6	10	Rejected
H7	11	Partially Accepted
H8	12	Accepted

Source: Author's own construction

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

This section synthesizes the study's main findings, illustrating the interconnectedness of climate drivers, household perceptions, vulnerability, and coping and adaptive strategies.

This study determines that pastoral vulnerability in Rayitu district is not driven primarily by rainfall variability but by a compounding set of structural forces: rapid and statistically significant warming, a drought regime marked by recurrent mild and intermittent severe events, and chronic deficits in water, grazing, and infrastructure access. While total annual precipitation shows no significant long-term trend, the sharp rise in temperature, particularly its negative effect on spring (Belg) season rainfall, is reshaping the risk landscape independently of precipitation totals alone.

Against this backdrop, pastoralists are aware of these changes. Their perceptions are coherent, internally consistent, and shaped by tangible experience with environmental and institutional conditions. Yet awareness alone does not translate into resilience. The evidence shows that physical and infrastructural accessibility, not resource endowment, is the primary determinant of vulnerability, with human and financial capital playing only a secondary, and in some respects incomplete, protective role. This finding challenges a purely asset-based view of vulnerability and points instead to infrastructure as the binding constraint on adaptive capacity.

Building on this, the study further shows that this capital configuration does not merely determine vulnerability levels instead it actively shapes behaviour. Asset-poor, infrastructure-deprived households' default to reactive, short-term coping (destocking, consumption reduction), while better-endowed households can pursue proactive, investment-oriented adaptation (herd diversification, resilient breeds, livelihood diversification). This divergence illustrates why uniform climate interventions fail: the same climatic shock produces fundamentally different household responses depending on capital access.

Collectively, these findings make a strong case that pastoralism's continued marginalization in policy is not just an equity concern but a practical failure of climate risk management. Interventions focused solely on short-term emergency relief or on building household assets in isolation are unlikely to achieve. Instead, durable resilience requires prioritizing infrastructure such as roads, water systems,

veterinary and health services, and training centres, as the foundation upon which human and financial capital investments can generate meaningful adaptive gains. Recognizing pastoralism's structural constraints, rather than treating it as a residual or backward livelihood system, is essential for designing climate policy that is both scientifically grounded and socially just.

4.2 Policy Recommendation and Implication

This part translates the findings into five intervention areas, each tied to a significant finding and mapped to the concerned government bodies and stakeholder institutions best positioned to implement them, including the Productive Safety Net Programme (PSNP), the Drought Resilience and Sustainable Livelihoods Programme (DRSLP), and relevant financial and extension service providers as follows,

i. Shift monitoring from annual to seasonal scale: Rayitu's annual rainfall shows no significant trend, yet this covers opposing intra-year shifts: September rainfall is declining, November rainfall is rising, and spring, the season contributing most to annual rainfall, shows a marginal decline. Annual-scale monitoring thus obscures the risk that matters most. The policy makers should recalibrate drought triggers to monthly/seasonal indicators, agro-climate advisories should revise autumn onset guidance, and monitoring frameworks should report seasonal alongside annual trends.

ii. Expand basic service infrastructure. Physical capital is the dominant contributor of vulnerability, followed by financial, human, social, and natural capital assets. Distance to health centres, training centres, veterinary posts, and water points is the strongest fault line, while natural capital contributes almost nothing. This points to decades of misplaced policy focus on land and herd size. Priority should shift toward health post coverage, siting veterinary/training centres within reach of mobile herders and developing dual-purpose water points.

iii. Expand financial inclusion. Credit, insurance, and remittance access show large, significant effects on vulnerability. Savings access reduces distress coping (casual labour, food intake reduction) and increases sustainable adaptation (herd/nonfarm diversification). As a lower-cost, faster lever than infrastructure, financial inclusion should be expanded through tailored livestock/drought-index insurance, microfinance and village

savings groups, mobile money/remittance channels, and SPEI-informed destocking incentives.

iv. Reorient cooperatives and extension around climate risk. Social capital's overall contribution is modest, but cooperative membership drives most of it, reducing destocking and increasing diversification; extension access similarly boosts diversification. However, veterinary extension access is negatively associated with climate change perception, indicating that extension services currently operate independently of climate messaging. Cooperatives should be reoriented around risk-sharing (fodder banks, joint water infrastructure, collective destocking), with climate-adaptive content integrated into extension delivery.

v. Secure rangeland access and herd mobility. Rangeland access significantly increases seasonal migration and the adoption of drought-tolerant livestock while reducing reliance on casual labour. As warming reduces the reliability of spring rainfall, mobility to track rainfall variability across other seasons becomes more critical, not less. Mobility is thus a measurable adaptive strategy under threat from land fragmentation. Governance bodies should treat corridor protection as core drought-resilience infrastructure, resist the fragmentation of communal grazing land, and formalise mobility rights within pastoral resilience programming.

4.3 Limitation and direction for future research

Although the study provides valuable insights into the vulnerability of pastoral households and their adaptation to climate change and variability, there are still some limitations that offer opportunities for further research, as mentioned below.

The study was conducted using a cross-sectional survey design and self-reported household responses. There are limitations in establishing a causal relationship between the identified determinants and climate change perceptions, and the results may be biased by response bias. Future research should therefore take a longitudinal approach integrating actual climatic and meteorological data with household perceptions to better understand how perceptions change in pastoralist communities and lead to specific adaptation practices.

This study constructs the vulnerability index using PCA-derived weights, which may be sensitive to indicator selection and scaling procedures. Consequently, alternative indicators, weighting approaches, or normalization methods could

produce different vulnerability scores and household rankings. To address this methodological limitation, future research should assess the sensitivity and robustness of the vulnerability index by testing alternative indicator sets, weighting schemes, and normalization methods. Such analysis would help determine the stability of vulnerability estimates and strengthen the reliability, comparability, and generalizability of vulnerability assessments in pastoral contexts.

This study inadequately addresses potential endogeneity between vulnerability, adaptation behaviour, and household characteristics, a problem that the cross-sectional models used cannot sort out. Future research should apply instrumental variable regression, panel data with fixed effects, or simultaneous equation modelling, along with longitudinal data collection, to better establish causal direction and capture how vulnerability and adaptation co-evolve over time.

This study compares its findings with existing international research, emphasising the necessity of more systematic comparisons across diverse contexts. Future research should conduct comparative analyses that encompass different countries and pastoral environments to identify similarities and differences arising from ecological, socioeconomic, and institutional conditions, thereby enhancing the generalisability of the findings and their scientific contribution.

5. NEW SCIENTIFIC RESULTS

This study provides some new empirical and methodological insights on climate variability, drought dynamics, perceptions of vulnerability and adaptation strategies among pastoral households in the Rayitu district and in Ethiopia's lowland pastoral areas as described below.

1. **Climate variability in Rayitu with no trend in annual precipitation, increasing rainfall concentration and dominance of mild drought, with strong, multi scale warming and season specific rainfall -temperature link.**

   Monthly rainfall in Rayitu shows high variability, except during April–May, with spring being the most stable and winter the least stable season. This confirms H1, indicating that the main climatic risk is the timing and distribution of rainfall rather than annual totals. The PCI shows that more than four-fifths of years have highly irregular rainfall, while SPI/SPEI results indicate that mild drought is dominant, with less frequent but clustered severe and extreme events. These findings support H3, highlighting a concentrated rainfall regime with recurrent, mostly mild but disruptive droughts. Temperature records also show a significant warming trend across monthly, seasonal, and annual scales, strongest in SON and JJA (about 0.3–0.4°C per decade). Spring and annual rainfall are strongly and negatively correlated with temperature, particularly Tmax, partially confirming H2 by indicating that warming has its clearest adverse effect during the main rainy season.

2. **Development of multi-index and multi scale drought monitoring framework for pastoral areas**

   The study establishes a three-tiered framework for drought monitoring in pastoral decision-making, combining precipitation concentration index (PCI), standard precipitation index (SPI), and standard precipitation evapotranspiration index (SPEI) for 3, 6, and 12 months: short-term (inter-seasonal), seasonal and bi-seasonal, and annual and multiannual. The findings suggest that acute seasonal stress (SPI, SPEI-3), persistent multi-seasonal deficits (SPI, SPEI-6), and occasional extreme drought events (SPEI, SPEI-12) are the cause of the collapse of herds and water systems. This integrated approach is a new methodological contribution to operational drought early warning in pastoral systems in Ethiopia.

3. **Pastoralists perceive and validate climate change more strongly through livelihood-based (indirect) impacts than through direct meteorological cues**.

   Indirect indicators recorded a higher mean recognition rate (79%) than direct climatic indicators (75%), with "drying up of grazing land" (91.5%) emerging as the single most recognised indicator of all twelve, even surpassing "decreased frequency of rainfall" (90.3%), which is the highest-ranked direct indicator. All indicators were statistically significant at different level, confirming that these perceptions are not random but reflect a consistent, shared cognitive pattern across the sampled households. Pastoralists' daily dependence on pasture, water, and livestock makes these changes more immediately tangible than gradual temperature or rainfall shifts. The result indicates that the knowledge system of pastoral households is outcome-oriented, reading climate change through ecosystem effects rather than meteorological parameters, which is supported by H4.

4. **Physical capital as the dominant axis of Pastoral vulnerability**

   Physical capital and accessibility were identified as the principal factors influencing the vulnerability of pastoral households. The distance to health centres (12.96%), veterinary clinics (12.13%), pastoral training centres (10.78%), and access to livestock water (10.57%) collectively constituted a substantial portion of this vulnerability. These findings challenge existing perspectives that have emphasized natural and financial capital as the primary determinants of pastoral vulnerability. The results suggest that vulnerability is determined not only by the availability of household resources but also by access to essential services, water, and supporting infrastructure, which determine pastoralists' ability to respond effectively and promptly to climate-related shocks as supported by H5.

5. **The livestock wealth Paradox: larger livestock holding increases rather than decreases vulnerability**

   Livestock holdings (TLU) significantly increase, rather than reduce, the vulnerability of pastoralists. This supports Hypothesis H6 while overturning the conventional assumption that livestock function as assets that buffer resilience. This finding is supported by Table 11, where livestock ownership was also the strongest predictor of perceptions of climate change, nomads with larger herds are, in fact, exposed to greater risks and therefore perceive those risks more acutely. This finding redefines livestock not as an asset that buffers against risk but as one that bears risk, calling into question existing livelihood-

capital theory and suggesting that insurance or diversification must accompany livestock accumulation to prevent increased vulnerability.

6. **Determinants of vulnerability distinguish structural risk enhancers from protective factors among pastoral households.**
   The ordinal logistic regression marginal effects result in Table 11, which provides a policy-relevant map of pastoral household vulnerability, clearly separating protective factors (formal education, skills training, financial capital instruments, and social/institutional networks) from structural risk enhancers (cumulative livelihood exposure, chronic health burden, and large livestock holdings), offering a more nuanced target for vulnerability-reduction interventions than a simple capital-endowment approach.
7. **Coping and adaptation strategies are structurally governed by distinct determinants of pastoral households.**
   The study findings indicate that coping and adaptation strategies follow different capital mobilization pathways. Livestock assets increase both destocking and the adoption of drought-resistant breeds, but they reduce herd diversity, whereas access to electricity reduces extreme coping responses. In contrast, savings do not significantly influence coping but promote adaptation based on diversification. These findings suggest that strengthening adaptive capacity does not necessarily reduce coping strategies, and they underscore the need for differentiated policies that address short-term coping and long-term adaptation separately. This serves as a useful complement to the "Sustainable Livelihoods Framework" for livestock development policies.

6. LIST OF PUBLICATIONS

1. **Gebbisa, M. B.,** & Bacsi, Z. (2024). Climate variability and adaptation strategies in a pastoralist area of the Eastern Bale Zone: the case of Sawena District, Ethiopia. *Applied Sciences*, *15*(1), 69.https://doi.org/10.3390/app15010069
2. **Gebbisa, M. B.,** Yasin, A. S., & Bacsi, Z. (2024). Impacts of Weather Variability on the International Tourism Receipts—Evidence from Ethiopia (1995–2019). *Tourism and Hospitality*, *5*(2), 416-438. https://doi.org/10.3390/tourhosp5020026
3. Andualem, H. M., **Mesfin Bekele Gebbisa,** & Zsuzsanna Bacsi (2025). *Wheat production across East Africa: Trend, instability, and decomposition analysis using time series approach. Journal of Sustainable Agriculture and Environment, 4*(2), e70073. https://doi.org/10.1002/sae2.70073
4. Yasin, A. S., **Gebbisa, M. B.,** & Bacsi, Z. (2024). *Sustainable rural tourism development in Ethiopia: Leveraging economic growth, infrastructure improvements, and cultural heritage. Journal of Infrastructure, Policy and Development, 8*(15), 9895. https://doi.org/10.24294/jipd.v8i15.9895
5. Zsuzsanna Bacsi, **Gebbisa, M. B.,** Lóránt Dénes Dávid, & Zsolt Hollósy (2023). *Pastoralism and tourism in Eastern Africa—Quantitative analysis from 2004 to 2018. Sustainability, 15*(12), 9723. https://doi.org/10.3390/su15129723

Other Scientific journal articles in English

6. **Gebbisa, M. B.,** & Bacsi, Z. (2025). Climate Change and Economic Growth: Evidence from Ethiopia for 1966-2021. *International Journal of Food and Agricultural Economics (IJFAEC)*, *13*(4), 287–303. https://doi.org/10.22004/ag.econ.374863

Conference papers

7. **Mesfin Bekele Gebbisa**. (2024). Rural Population Growth and Economic Development Indicators in Ethiopia. In: Földi, Péter; Viktor, Patrik (eds.) III. rural areas in the 21st century scientific conference, May 22, 2024, in Gyöngyös, Hungary.
8. **Gebbisa, M.B and Zsuzsanna Bacsi**. (2023). Pastoralism and its direct economic value in the Oromiya region, Ethiopia. Presented at the 29th Youth Scientific Forum hold on June 8, 2023, in Keszthely, Hungary.
9. **Mesfin Bekele Gebbisa & Zsuzsanna Bacsi. (2026).** Digitalisation and climate-resilient governance in European countries: Using panel data. In *Book of abstracts: Reframing climate resilience—The transformative role of social sciences, humanities and the arts: A SHiFT Conference on Knowledge, Governance and Public Policy* (pp. 15–16), Lisbon, Portugal.

7. REFERENCES

1. Abate, G. T., Dereje, M., Hirvonen, K., & Minten, B. (2020). Geography of public service delivery in rural Ethiopia. *World Development, 136*, 105133. https://doi.org/10.1016/j.worlddev.2020.105133
2. Abay, K. A., Abay, M. H., Berhane, G., & Chamberlin, J. (2022). Social protection and resilience: The case of the Productive Safety Net Program in Ethiopia. *Food Policy, 112*, 102367. https://doi.org/10.1016/j.foodpol.2022.102367
3. Abduletif, A. A. (2019). Benefits and challenges of the pastoralism system in Ethiopia. *Studia Mundi–Economica, 6*(3), 56–67. https://doi.org/10.18531/Studia.Mundi.2019.06. 03.56-67
4. Abrham, T., & Mekuyie, M. (2022). Effects of climate change on pastoral households in the Harshin District of the Somali Region, Ethiopia. *Jàmbá: Journal of Disaster Risk Studies, 14*(1), a1202. https://doi.org/10.4102/jamba.v14i1.1202
5. Addis, E., Negatu, W., & Simane, B. (2021). *Households' vulnerability to climate change in drought-prone agro-ecosystems of northeastern Ethiopia*. *Journal of Natural Sciences Research, 12*(5), 56–74. https://doi.org/10.7176/JNSR/13-5-05
6. Akafu, T. (2025). Farmers' perceptions and adaptation strategies to climate change and variability in the Gobu Sayo district, Western Ethiopia. *Sustainable Environment, 11*(1), 2494365. https://doi.org/10.1080/27658511.2025.2494365
7. Alemayehu, S., Olago, D., Alfred, O., Zeleke, T. T., & Dejene, S. W. (2024). Spatiotemporal analysis of rainfall and temperature variability and trends for a mixed crop–livestock production system: Its implications for developing adaptation strategies. *International Journal of Climate Change Strategies and Management, 17*(1), 268–290. https://doi.org/10.1108/IJCCSM-08-2024-0133
8. Alemayehu, A., & Bewket, W. (2017). Determinants of smallholder farmers' choice of coping and adaptation strategies to climate change and variability in the central highlands of Ethiopia. *Environmental Development, 24*, 77–85. https://doi.org/10.1016/ j.envdev. 2017.06.006
9. Alemu, G., & Worku, K. (2017). GIS-based land-use suitability analysis for selected perennial crops in Gumay Woreda of Jimma Zone, Southwest Ethiopia. *Ethiopian Journal of Social Sciences and Language Studies,* 4(1), 3–18. Retrieved from http://www.ju. Edu.et/cssljournal
10. Alotaibi, B. A., Abbas, A., Ullah, R., Azeem, M. I., Samie, A., Muddassir, M., Dabiah, A. T., Raid, M., & Sadaf, T. (2023). Dynamics and determinants of farmers' perceptions about causes and impacts of climate change on agriculture in Saudi Arabia: Implications for adaptation, mitigation, and sustainability. *Atmosphere, 14*(6), 917. https://doi.org/10.3390/ atmos14060917
11. Asfaw, A., Bantider, A., Simane, B., & Hassen, A. (2021b). Smallholder farmers' livelihood vulnerability to climate change-induced hazards: Agroecology-based comparative analysis in Northcentral Ethiopia (Woleka Sub-basin). *Heliyon, 7*(4), e06761. https://doi.org/10.1016/j.heliyon. 2021 .e06761
12. Asfaw, A., Simane, B., Hassen, A., & Bantider, A. (2018). Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. *Weather and Climate Extremes, 19*, 29–41. https://doi.org/10.1016/ j.wace. 2017. 12.002
13. Ashford, J. R., & Sowden, R. R. (1970). Multi-variate probit analysis. Biometrics, 535-546. https://doi.org/10.2307/2529107
14. African Union (AU) (2010). *Policy framework for pastoralism in Africa: Securing, protecting and improving the lives, livelihoods and rights of pastoralist communities.* https://au.int/sites/default/files/documents/30240-doc-policy_framework_ for_pastoralism.pdf

15. Aytenfisu, A. T., Tolossa, D., Feleke, S. T., & Ayal, D. Y. (2024). Spatiotemporal climate variability and extremes in the Middle Awash Afar region, Ethiopia: Implications to pastoralists and agro-pastoralists' food security. *International Journal of Climate Change Strategies and Management, 16*(2), 228–252. https://doi.org/10.1108/IJCCSM-11-2023-0140
16. Ayugi, B., Dike, V., Ngoma, H., Babaousmail, H., Mumo, R., & Ongoma, V. (2021). Future changes in precipitation extremes over East Africa based on CMIP6 models. *Water, 13*(17), 2358. https://doi. org/10.3390/w13172358
17. Bacsi, Z., Gebbisa, M. B., Dávid, L. D., & Hollósy, Z. (2023). Pastoralism and tourism in Eastern Africa—Quantitative analysis from 2004 to 2018. *Sustainability, 15*(12), 9723. https://doi.org/10.3390/ su15129723
18. Barrow, E. (2022). *Pastoralists—the solution to sustainable dry landscape management, yet undermined and seen as the "problem".* Rights and Resources. https://doi.org/10.53892/TZSU2442
19. Becker, H. S. (1964). Personal change in adult life. *Sociometry*, 40-53. https://doi.org/10.2307/2785801
20. Bedo, D., Mekuriaw, A., & Bantider, A. (2024). Adaptive responses and determinants of adaptation decisions to climate change: evidence from rainfed-dependent farmers in the Central Rift Valley of Ethiopia. *Cogent Food & Agriculture*, *10*(1), 2430404.https://doi.org/10.1080/23311932.2024.2430404
21. Behnke, R., & Kerven, C. (2013). Counting the costs: replacing pastoralism with irrigated agriculture in the Awash Valley. In *Pastoralism and Development in Africa* (pp. 57-70). Routledge.
22. Belay, A., Recha, J. W., Woldeamanuel, T., & Morton, J. F. (2017). Smallholder farmers' adaptation to climate change and determinants of their adaptation decisions in the Central Rift Valley of Ethiopia. *Agriculture & Food Security, 6*(1), 24. https://doi.org/10.1186/s40066-017-0100-1
23. Berhanu, W., & Beyene, F. (2015). Climate variability and household adaptation strategies in southern Ethiopia. *Sustainability, 7*(6), 6353–6375. https://doi.org/10.3390/su7066353
24. Berihun, M. L., Tsunekawa, A., Haregeweyn, N., Tsubo, M., Yasuda, H., Fenta, A. A., Dile, Y. T., Bayabil, H. K., & Tilahun, S. A. (2023). Examining the past 120 years' climate dynamics of Ethiopia. *Theoretical and Applied Climatology, 154*, 535–566. https://doi.org/10.1007/s00704-023-04572-4
25. Chambers, R., & Conway, G. R. (1992). *Sustainable rural livelihoods: Practical concepts for the 21st century* (IDS Discussion Paper No. 296). Institute of Development Studies. https://www.ids.ac.uk/publications/sustainable-rural-livelihoods-practical-concepts-for-the-21st-century/
26. Coalition of European Lobbies for Eastern African Pastoralism (CELEP) (2017). *Recognising the role and value of pastoralism and pastoralists* (Policy Brief No. 1). https://www.celep.info/wp-content/uploads/2017/05/Policybrief-CELEP-May-2017-Value-of-pastoralism.pdf
27. Cherinet, A., Simane, B., & Asmare, A. M. (2025). Climate Change Adaptation Strategies and Determinants of Adoption Among Smallholder Farmers in Jemma Sub-basin, Central Ethiopia. *IDRiM Journal, 15*(2). https://doi.org/10.5595/001c.143101
28. Cox. D.R (1958). *The regression analysis of binary sequences*. *Journal of the Royal Statistical Society: Series B (Methodological), 20*(2), 215–232. https://doi.org/10.1111/j.2517-6161.1958.tb00292.x
29. Creswell, J. W. (2014). *Research design: Qualitative, quantitative, and mixed methods approach* (4th ed.). Sage. https://www.ucg.ac.me/skladiste/blog_609332/objava_105202/fajlovi/Creswell.pdf

30. Debela, N., Mohammed, C., Bridle, K., Corkrey, R., & McNeil, D. (2015). Perception of climate change and its impact by smallholders in pastoral/agropastoral systems of Borana, South Ethiopia. *SpringerPlus, 4*(1), 236. https://doi.org/10.1186/s40064-015-1012-9
31. Degefu, M., Assen, M., Satyal, P., & Budds, J. (2019). Villagization and access to water resources in the Middle Awash Valley of Ethiopia: Implications for climate change adaptation. *Climate and Development, 12*(10), 899–910. https://doi.org/ 10.1080/ 17565529.2019. 1701973
32. Dejene, T., Dalle, G., Woldeamanuel, T., & Mekuyie, M. (2023). Temporal climate conditions and spatial drought patterns across rangelands in pastoral areas of West Guji and Borana zones, Southern Ethiopia. *Pastoralism, 13*, 18. https://doi.org/10.1186/s13570-023-00278-4
33. Dejene, T. (2020). *Guji pastoral household vulnerability to climate change in Malka Soda District, Ethiopia*. *PalArch's Journal of Archaeology of Egypt/Egyptology, 17*(12), 438–462. https:// archives.palarch.nl/index.php/jae/article/view/6082
34. Department for International Development (DFID) (1999). *Sustainable livelihoods guidance sheets*.https://www.livelihoodscentre.org/documents/114097690/114438878/Sustainable+livelihoods+guidance+sheets.pdf
35. Dinku, A. M. (2018). Determinants of livelihood diversification strategies in Borena pastoralist communities of Oromia regional state, Ethiopia. *Agriculture & Food Security, 7*, 41. https://doi.org/10.1186/s40066-018-0192-2
36. Duba, G. W. (2022). Rainfall trend and variability analysis in Borana pastoral lowland areas: The case of Yabello and Eel-wayye Station, Southern Ethiopia. *International Journal of Environmental Monitoring and Analysis, 10*(1), 16–25. https://doi.org/ 10.11648/ j.ijema. 20221001.13
37. Duba, W. G., Solomon, T., & Tegegne, S. (2021). Determinant's choices of drought coping strategies among Borana pastoral communities: The case of Yabello Woreda, Oromiya Region, Southern Ethiopia. *American Journal of Life Sciences, 9*(4), 73–80. https://doi.org/10.11648/j.ajls. 20210904.13
38. Ellis, J. E., & Swift, D. M. (1988). Stability of African pastoral ecosystems: Alternate paradigms and implications for development. *Journal of Range Management*, *41*(6), 450–459. https://doi.org/10.2307/3899515
39. Ewalo, W., & Vedeld, P. (2023). Climate change in the Sidama region, Ethiopia: linking perceptions and adaptation. *GeoJournal*, *88*(6), 5775. https://doi.org/10.1007/s10708-023-10941-3
40. Federal Democratic Republic of Ethiopia (FDRE) (2021). *Updated nationally determined contribution*.https://www.epa.gov.et/images/PDF/NDC/Ethiopia_2021_Plan_NDC%20Update%20Technical%20Report.pdf
41. Federal Democratic Republic of Ethiopia (FDRE) (1995). *Proclamation No. 1/1995: A proclamation to pronounce the coming into effect of the Constitution. Federal Negarit Gazeta,* 1st Year, No. 1. https://www.ethiopianembassy.be/wp-content/uploads/Constitution-of-the-FDRE.pdf
42. Fenta, M., Jordaan, A., & Melka, Y. (2019). Vulnerability of Southern Afar pastoralists to climate variability and change, Ethiopia. *Jàmbá: Journal of Disaster Risk Studies, 11*(1), a575. https://doi.org/10.4102/jamba.v11i1.575
43. Feyera, T., Mekonnen, E., Wakayo, B. U., & Assefa, S. (2017). Botanical ethnoveterinary therapies used by agro-pastoralists of Fafan zone, Eastern Ethiopia. *BMC Veterinary Research, 13*, Article 232. https://doi.org/10.1186/s12917-017-1149-6
44. Feyissa, A. A., Angassa, A., & Tadesse, M. (2025). Are climate change adaptation strategies interrelated? Evidence from Borana pastoral communities, southern Ethiopia. *Frontiers in Climate, 7*, 1545422. https://doi.org/10.3389/fclim.2025.1545422

45. Gashure, S., & Wana, D. (2023). Smallholder farmers' perceptions, coping and adaptation strategies to climate variability in the UNESCO-designated cultural landscapes of Konso, Ethiopia. *Local Environment, 28*(10), 1243–1262. https://doi.org/10.1080/ 13549839.2023.2202379
46. Gatew, S., & Guyo, N. (2024). Livelihood vulnerability of Borana pastoralists to climate change and variability in Southern Ethiopia. *International Journal of Climate Change Strategies and Management, 16*(1), 157–176. https://www.emerald.com/insight/1756-8692.htm
47. Gebbisa, M. B., & Bacsi, Z. (2025). Climate variability and adaptation strategies in a pastoralist area of the Eastern Bale Zone: The case of Sawena District, Ethiopia. *Applied Sciences, 15*(1), 69. https://doi.org/10.3390/app15010069
48. Gebeyehu, A. K., Snelder, D., Sonneveld, B., & Abbink, J. (2021). How do agro-pastoralists cope with climate change? The case of the Nyangatom in the Lower Omo Valley of Ethiopia. *Journal of Arid Environments, 189*, 104485. https://doi.org/10.1016/j.jaridenv.2021.104485
49. Gebre, B., Ayenew, H. Y., & Biadgilign, S. (2021). Drought, hunger, and coping mechanisms among rural households in Southeast Ethiopia. *Heliyon, 7*(3), e06355. https://doi.org/10.1016/j.heliyon.2021 .e06355.
50. Gebrehiwot, T., & Hassen, S. (2022). *Impact of energy access on food security and child nutrition: Panel data evidence from rural Ethiopia* (EfD Discussion Paper No. 22-11). Environment for Development, University of Gothenburg. https://ideas.repec.org/p/hhs/gunefd/2022_011.html
51. Gebremeskel, E. N., Desta, S., & Kassa, G. K. (2019). *Pastoral development in Ethiopia: Trends and the way forward* (Development Knowledge and Learning). World Bank. https://doi.org/10. 1596/31818
52. Ghosh, M., & Ghosal, S. (2020). Determinants of household livelihood vulnerabilities to climate change in the Himalayan foothills of West Bengal, India. *International Journal of Disaster Risk Reduction, 50*, 101706. https://doi.org/10.1016/j.ijdrr.2020.101706
53. Greene, W. H. (2002). *Econometric analysis* (5th ed.). Prentice Hall. ISBN: 9780130661890.
54. Guye, M. H., Legesse, A., & Mohammed, Y. (2023). Existential threats to pastoralism in an arid environment: The fate of Gujii pastoralists in Southern Ethiopia. *Journal of Degraded and Mining Lands Management, 10*(2), 4179–4190. https://doi.org/ 10.15243/jdmlm.2023.102.4179
55. Habtemariam, L. T., Gandorfer, M., Kassa, G. A., & Heissenhuber, A. (2016). Factors influencing smallholder farmers' climate change perceptions: A study from farmers in Ethiopia. *Environmental Management, 58*(2), 343–358. https://doi.org/10.1007/s00267-016-0708-0
56. Hassan, R.M. (1996) Planting Strategies of Maize Farmers in Kenya: A Simultaneous Equations Analysis in the Presence of Discrete Dependent Variables. Journal of Agricultural Economics, 15, 137-149. https://doi.org/10.1016/S0169-5150(96)01194-2
57. Hotelling, H. (1933). Analysis of a complex of statistical variables into principal components. *Journal of Educational Psychology, 24*(6), 417–441. https://doi.org/10.1037/h0071325
58. IGAD Centre for Pastoral Areas and Livestock Development (ICPALD) (2020). *Total economic valuation of pastoralism in Ethiopia: Study report*. https://icpald.org/wp-content/uploads/2021/02/Total-Economic-Valuation-of-Pastoralism-in-Ethiopia.pdf
59. Idrissou, Y., Assani, A. S., Baco, M. N., & Alkoiret Traoré, I. (2021). Determinants of cattle farmers' perception of climate change in the dry and subhumid tropical zones of Benin (West Africa). In *African Handbook of Climate Change Adaptation* (pp. 197–212). Springer. https://doi.org/10. 1007/978-3-030-45106-6_16
60. Johnson, R. B., Onwuegbuzie, A. J., & Turner, L. A. (2007). Toward a definition of mixed methods research. *Journal of Mixed Methods Research, 1*(2), 112–133. https://doi.org/10.1177/ 1558689806298224

61. Kaiser, H. F. (1974). An index of factorial simplicity. *Psychometrika, 39*(1), 31–36. https://doi.org/ 10.1007/BF02291575
62. Kemal, A. W., Mohammed, A. A., & Lelamo, L. L. (2022). Pastoralists' adaptation strategies to climate change and determinant factors in Korahey Zone, Ethiopia. *American Journal of Climate Change, 11*(2), 79–102. https://doi.org/10.4236/ajcc.2022.112005
63. Kendall, M. G. (1975). *Rank correlation methods* (4th ed.). Griffin. https://worldcat.org/ title/ 491952877
64. Kimutai, J., Barnes, C., Zachariah, M., Philip, S. Y., Kew, S. F., Pinto, I., Wolski, P., Koren, G., Vecchi, G., Yang, W., Li, S., Vahlberg, M., Singh, R., Heinrich, D., Arrighi, J., Marghidan, C. P., Thalheimer, L., Kane, C., Raju, E., & Otto, F. E. L. (2025). Human-induced climate change increased the 2021–2022 drought severity in the Horn of Africa. *Weather and Climate Extremes, 47*, 100745. https://doi.org/10.1016/j.wace.2025.100745
65. Kothari, C. R. (2004). *Research methodology: Methods and techniques* (2nd ed.). New Age International.https://ndl.ethernet.edu.et/bitstream/123456789/79439/5/Research%20 Methodology%20-20Methods%20and%20Techniques %202004.pdf
66. Kourouma, J. M., Eze, E., Kelem, G., Negash, E., Phiri, D., Vinya, R., Girma, A., & Zenebe, A. (2022). Spatiotemporal climate variability and meteorological drought characterization in Ethiopia. *Geomatics, Natural Hazards and Risk, 13*(1), 2049–2085. https://doi.org/10.1080/19475705. 2022.2106159
67. Lankamo, A. A., R, D., Bati, B. E., & Dira, S. J. (2025). Confronting the uncertainty: Vulnerability to climate change among smallholder farmers in the Sidaama region, Ethiopia. *Plos one*, *20*(5), e0323469. https://doi.org/10.1371/journal.pone.0323469.
68. Lavell, A., Oppenheimer, M., Diop, C., Hess, J., Lempert, R., Li, J., & Myeong, S. (2012). Managing the risks of extreme events and disasters to advance climate change adaptation. In *A special report of Working Groups, I and II of the IPCC* (pp. 25–64).
69. Letsoalo, N., Samuels, I., Cupido, C., Ntombela, K., Finca, A., Foster, J., Tjelele, J., & Knight, R. (2023). Coping and adapting to drought in semi-arid Karoo rangelands: Key lessons from livestock farmers. *Journal of Arid Environments, 219*, 105070. https://doi.org/10.1016/j.jaridenv.2023. 10507
70. Lever, J., Krzywinski, M., & Altman, N. (2017). Principal component analysis. *Nature Methods, 14*(7), 641–642. https://doi.org/10.1038/nmeth.4346
71. Makula, E. K., Mangara, R. J., Kazimili, B., Mbigi, D., Mtewele, Z. F., Kebacho, L. L., Kessy, W. P., & Limbu, P. T. S. (2025). Assessment of drought characteristics using SPEI and VHI in Tanzania and their associated climate factors. *Natural Hazards, 121*(2), 2071–2093. https://doi.org/10.1007/ s11069-024-06894-6
72. Manzano, P., Burgas, D., Cadahía, L., Eronen, J. T., Fernández-Llamazares, Á., Bencherif, S., Holand, Ø., Seitsonen, O., Byambaa, B., Fortelius, M., Fernández-Giménez, M. E., Galvin, K. A., Cabeza, M., & Stenseth, N. C. (2021). Toward a holistic understanding of pastoralism. *One Earth, 4*(5), 651–665. https://doi.org/10.1016/j.oneear.2021.04.012
73. Mann H.B (1945). *Nonparametric tests against trend*. *Econometrica, 13*(3), 245–259. https://doi.org/10.2307/1907187.
74. Maziya, M., & Nkonki-Mandleni, B. (2024). Socio-economic determinants of climate change perception in the uMkhanyakude district of KwaZulu-Natal province, South Africa. *Journal of Agribusiness and Rural Development, 72*(2), 225–237. https://doi.org/10.17306/ j.jard.2024.01820
75. Mbow, C., Rosenzweig, C., Barioni, L. G., Benton, T. G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M. G., Sapkota, T., Tubiello, F. N., & Xu, Y. (2019). Food security. In *Climate change and land: An IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems* (pp. 437–550). https://www.ipcc.ch/srccl/.

76. McDermaid, K. K., & Barnstable, D. C. (2001). *Step-by-step guide to conducting a social profile for watershed planning*. University of Illinois, Department of Natural Resources and Environmental Sciences. https://www.csu.edu/cerc/researchreports/documents/StepByStepGuideWatershedPlanning2001.pdf
77. McKee, T. B., Doesken, N. J., & Kleist, J. (1993). The relationship of drought frequency and duration to the time scale. In *Proceedings of the Eighth Conference on Applied Climatology* (179–184). American Meteorological Society. https://www.drought management.info/literature/AMS_Relationship_Drought_Frequency_Duration_Time_ Scales_1993.pdf
78. Megersa, G. G., Jaleta, M., Tesfaye, K., Getnet, M., Tana, T., & Lakew, B. (2022). Perceived climate change and determinants of adaptation responses by smallholder farmers in Central Ethiopia. *Sustainability, 14*(11), 6590. https://doi.org/10.3390/su14116590
79. Megersa, B., Markemann, A., Angassa, A., Ogutu, J. O., Piepho, H. P., & Valle Zárate, A. (2014). Livestock diversification: An adaptive strategy to climate and rangeland ecosystem changes in southern Ethiopia. *Human Ecology, 42*(4), 509–520. https://doi.org/10.1007/s10745-014-9668-2
80. Mekuyie, M., & Mulu, D. (2021). Perception of impacts of climate variability on pastoralists and their adaptation/coping strategies in Fentale district of Oromia Region, Ethiopia. *Environmental Systems Research, 10*(1), 4. https://doi.org/10.1186/s40068-020-00212-2
81. Mekuyie, M. (2021). Vulnerability of rural households to climate-induced shocks in Lokka Abaya district, Sidama zone, southern Ethiopia. *Jàmbá: Journal of Disaster Risk Studies, 13*(1), a1051. https://doi.org/10.4102/jamba.v13i1.1051
82. Mengistu, D., & Haji, M. (2015). Factors affecting the choices of coping strategies for climate extremes: The case of Yabello District, Borana Zone, Oromia National Regional State, Ethiopia. *Science Research, 3*(4), 129–136. https://doi.org/ 10.11648/ j.sr. 20150304. 11
83. Mera, G. A. (2018). Drought and its impacts in Ethiopia. *Weather and climate extremes*, *22*, 24-35. https://doi.org/10.1016/j.wace.2018.10.002
84. Meteoblue. (2025). *Weather History Database*. Retrieved April 10,2025 https://www.meteoblue.com/en/ history plus
85. Mihiretu, A., Okoyo, E. N., & Lemma, T. (2019). Determinants of adaptation choices to climate change in agro-pastoral drylands of North-eastern Amhara, Ethiopia. *Cogent Environmental Science, 5*(1), 1636548. https://doi.org/10.1080/23311843.2019.1636548
86. Ministry of Agriculture (MoA) (2012). *Ethiopia country programming paper to end drought emergencies in the Horn of Africa*. https://resilience.igad.int/wp-content/uploads/2020/10/To-end-drought-emergencies-in-the-Horn-of-Africa-Ethiopia. pdf
87. Mohamed, A. A. (2019). Pastoralism and development policy in Ethiopia: A review study. *Budapest International Research and Critics Institute (BIRCI-Journal)*, *2*(4), 1–11. https://doi.org/10.33258 /birci.v2i4.562
88. Molla, S. D., Zeleke, M. T., & Tamiru, S. M. (2024). Assessing livelihood resilience in drought-affected areas: Lessons from Raya Kobo district, northeast Ethiopia. *Heliyon, 10*(1), e23399. https://doi.org/10.1016/j.heliyon.2023.e23399
89. Moser, C. O. (1998). The asset vulnerability framework: reassessing urban poverty reduction strategies. *World development*, *26*(1), 1-19.
90. National Planning Commission (NPC) (2016). *Growth and Transformation Plan II (GTP II)* (2015/16–2019/20): *Volume I: Main text*. https://faolex.fao.org/docs/pdf/eth144893.pdf
91. Ndiritu, S. W. (2021). Drought responses and adaptation strategies to climate change by pastoralists in the semi-arid area, Laikipia County, Kenya. *Mitigation and Adaptation Strategies for Global Change, 26*(3), 10. https://doi.org/10.1007/s11027-021-09949-2
92. Nyamai, D. M. K., Amwata, D. A., & Kilungo, J. (2024). Perceptions of climate change and their determinants among the smallholder farmers in Machakos County. *International Journal of Advanced Research, 12*(6), 921–937. https://doi.org/10.21474/IJAR01/18956

93. Oliver, J. E. (1980). Monthly precipitation distribution: A comparative index. *The Professional Geographer, 32*(3), 300–309. https://doi.org/10.1111/j.0033-0124.1980.00300.x
94. Oromia Planning and Economic Development Commission (OPEDC) (2025). *Oromiya Regional State in brief Part-V*. Retrieved August 10,2025 from *https://www.oromiaplan. gov. et/om/content/qoannoo*
95. Opiyo, F., Wasonga, O. V., Nyangito, M. M., Mureithi, S. M., Obando, J., & Munang, R. (2016). Determinants of perceptions of climate change and adaptation among Turkana pastoralists in northwestern Kenya. *Climate and Development, 8*(2), 179–189. https://doi.org/10.1080/ 17565529.2015.1034231
96. Opiyo, F., Wasonga, O., Nyangito, M., Schilling, J., & Munang, R. (2015). Drought adaptation and coping strategies among the Turkana pastoralists of northern Kenya. *International Journal of Disaster Risk Science, 6*(3), 295–309. https://doi.org /10.1007/ s13753-015-0063-4
97. Opiyo, F. E. O., Wasonga, O. V., & Nyangito, M. M. (2014). Measuring household vulnerability to climate-induced stresses in pastoral rangelands of Kenya: Implications for resilience programming. *Pastoralism: Research, Policy and Practice, 4*, Article 10. https://doi.org/10.1186 /s13570-014-0010-9
98. Pearson, K. (1896). VII. Mathematical contributions to the theory of evolution.—III. Regression, heredity, and panmixia. *Philosophical Transactions of the Royal Society of London. Series A, containing papers of a mathematical or physical character*, (187), 253-318. https://doi.org/10.1098/rsta.1896.0007
99. Pearson, K. (1900). X. On the criterion that a given system of deviations from the probable in the case of a correlated system of variables is such that it can be reasonably supposed to have arisen from random sampling. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*, *50*(302), 157-175. https://doi.org/10.1080/ 14786440009463897
100. Pearson K. (1901). *On lines and planes of closest fit to systems of points in space*. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 2*(11), 559–572. https://doi.org/10.1080/14786440109462720
101. Pienaah, C. K. A., & Luginaah, I. (2024). The impact of village savings and loan associations as a financial and climate resilience strategy for mitigating food insecurity in Northern Ghana. *Risks, 12*(4), 58. https://doi.org/10.3390/risks12040058
102. Ragasa, G. A. (2025). Pastoralists' choices and determinants of climate change adaptation strategies: Evidence from Teltele District, Oromia Regional State, Ethiopia. *Indonesian Journal of Interdisciplinary Research in Science and Technology (MARCOPOLO), 3*(5), 541–560. https://doi.org/10.55927/marcopolo.v3i5.45
103. Rogers, R. W. (1975). A protection motivation theory of fear appeals and attitude change. *The Journal of Psychology, 91*(1), 93–114. https://doi.org/10.1080/00223980.1975.9915803
104. Saguye, T. S. (2017). Farmers' perception of climate variability and change and its implications for the implementation of climate-smart agricultural practices. *American Journal of Human Ecology, 6*(1), 27–41. https://doi.org/10.11634/216796221706822
105. Sahilu, M., Tekalign, S., Mohammed, Y., Sishaw, T., Kedir, H., & Asfaw, S. (2024). Spatiotemporal trends and variability of rainfall across agro-ecologies in East Guji Zone, Southeast Ethiopia. *PLOS Climate, 3*(3), e0000361. https://doi.org/10.1371/journal.pclm. 0000361
106. Schultz, T. W. (1961). Investment in human capital: reply. *The american economic review*, *51*(5), 1035-1039. https://www.jstor.org/stable/1813848
107. Scoones, I. (1998). *Sustainable rural livelihoods: A framework for analysis* (IDS Working Paper 72). Institute of Development Studies. https://www.ids.ac.uk/publications/sustainable-rural-livelihoods-a-framework-for-analysis/

108. Sen, P. K. (1968). Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association, 63*(324), 1379–1389.https://doi.org/10.1080/01621459. 1968.10480934
109. Shapiro, B. I., Gebru, G., Desta, S., Negassa, A., Nigussie, K., Aboset, G., & Mechale, H. (2017). *Ethiopia livestock sector analysis: A 15-year livestock sector strategy* (ILRI Project Report). International Livestock Research Institute (ILRI). https://hdl.handle.net/10568/92057
110. Shigute, M., Alamirew, T., Abebe, A., Ndehedehe, C. E., & Kassahun, H. T. (2023). Analysis of rainfall and temperature variability for agricultural water management in the Upper Genale River Basin, Ethiopia. *Scientific African, 20*, e01635. https://doi.org/10.1016/j.sciaf.2023.e01635
111. Silvestri, S., Bryan, E., Ringler, C., Herrero, M., & Okoba, B. (2012). Climate change perception and adaptation of agro-pastoral communities in Kenya. *Regional Environmental Change, 12*(4), 791–802. https://doi.org/10.1007/s10113-012-0293-6
112. Sintayehu, D. W., Alemayehu, S., Terefe, T., Tegegne, G., Engdaw, M. M., Gebre, L., & Girvetz, E. (2025). Effects of drought on livestock production, market dynamics, and pastoralists' adaptation strategies in semi-arid Ethiopia. *Climate, 13*(4), 65. https://doi.org/10.3390 /cli13040065
113. Snaibi, W., Mezrhab, A., Sy, O., & Morton, J. F. (2021). Perception and adaptation of pastoralists to climate variability and change in Morocco's arid rangelands. *Heliyon, 7*(11), e08434. https://doi.org/10.1016/j.heliyon.2021.e08434
114. Tadesse, S., Mekuriaw, A., & Assen, M. (2024). Spatiotemporal climate variability and trends in the Upper Gelana Watershed, northeastern highlands of Ethiopia. *Heliyon, 10*(5), e27274. https://doi.org/ 10.1016/j.heliyon.2024.e27274
115. Tasnuva, A., Hossain, M. R., Salam, R., Islam, A. R. M. T., Patwary, M. M., & Ibrahim, S. M. (2021). Employing the social vulnerability index to assess household social vulnerability to natural hazards: Evidence from southwest coastal Bangladesh. *Environment, Development and Sustainability, 23*(7), 10223–10245. https://doi.org/10.1007/s10668-020-01054-9
116. Teka, A. M., Woldu, G. T., & Fre, Z. (2022). Status and determinants of poverty and income inequality in pastoral and agro-pastoral communities: Household-based evidence from Afar Regional State, Ethiopia. *Social protection, pastoralism and resilience in Ethiopia: Lessons for Sub-Saharan Africa* (pp. 83–115). Routledge. https://doi.org/10.4324/9781003203513-4
117. Tesfahunegn, G. B., Mekonen, K., & Tekle, A. (2016). Farmers' perception on causes, indicators, and determinants of climate change in northern Ethiopia: Implications for developing adaptation strategies. *Applied Geography, 73*, 1–12. https://doi.org/10.1016/j.apgeog. 2016.05.009
118. Tesfamariam, B. G., Gessesse, B., & Melgani, F. (2019). Characterizing the spatiotemporal distribution of meteorological drought as a response to climate variability: The case of Rift Valley Lakes Basin of Ethiopia. *Weather and Climate Extremes, 26*, 100237. https://doi.org/10.1016/j.wace. 2019. 100237
119. Tilahun, F., & Legese, B. (2020). Major climate change adaptation and coping strategies in Borana, Southern Ethiopia: A review. *Journal of Resources Development and Management, 69*, 1–8. https://doi.org/10.7176/JRDM/69-01
120. Tofu, A. D., & Dedefa, G. D. (2018). Farm household vulnerability to climate change and its determinants: The case of Ada'a Berga District of West Shewa, Ethiopia. *Journal of Scientific Research and Reports, 21*(3), 1–17. https://doi.org/10.9734/JSRR/2018/41583
121. Tofu, D. A., & Mengistu, M. (2023). Observed time series trend analysis of climate variability and smallholder adoption of new agricultural technologies in West Shewa, Ethiopia. *Scientific African, 19*, e01448. https://doi.org/10.1016/j.sciaf.2022.e01448
122. Tofu, D. A., Dilbato, T., Fana, C., Dirbaba, N. B., & Tesso, G. (2025). Analysis of vulnerability, its drivers, and strategies applied towards reducing the pastoral and agro-

pastoral livelihood vulnerability to climatic shocks. *Scientific Reports, 15*, 2567. https://doi.org/10.1038/s41598-024-79165-w
123. Tolera, T., & Senbeta, F. (2020). Pastoral system in the face of climate variability: Household adaptation strategies in Borana rangelands, Southern Ethiopia. *Environment, Development and Sustainability, 22*(4), 3133–3157. https://doi.org/10.1007/s10668-019-00339-y
124. Turner, B. L., II, Kasperson, R. E., Matson, P. A., McCarthy, J. J., Corell, R. W., Christensen, L., Eckley, N., Kasperson, J. X., Luers, A., Martello, M. L., Polsky, C., Pulsipher, A., & Schiller, A. (2003). A framework for vulnerability analysis in sustainability science. *Proceedings of the National Academy of Sciences, 100*(14), 8074–8079. https://doi.org/10.1073/pnas.123133510
125. Tsegaye, D., Vedeld, P., & Moe, S. R. (2013). Pastoralists and livelihoods: A case study from northern Afar, Ethiopia. *Journal of Arid Environments, 91*, 138–146. https://doi.org/10.1016/j.jaridenv.2013.01.002
126. Tversky, A., & Kahneman, D. (1973). Availability: A heuristic for judging frequency and probability. *Cognitive Psychology, 5*(2), 207–232. https://doi.org/10.1016/0010-0285(73)90033-9
127. Uddin, M. N., Islam, A. S., Bala, S. K., Islam, G. T., Adhikary, S., Saha, D., & Akter, R. (2019). Mapping of climate vulnerability of the coastal region of Bangladesh using principal component analysis. *Applied Geography, 102*, 47–57. https://doi.org/10.1016/j. apgeog. 2018.12.011
128. Vicente-Serrano, S. M., Beguería, S., & López-Moreno, J. I. (2010). A multiscalar drought index sensitive to global warming: The Standardized Precipitation Evapotranspiration Index (SPEI). *Journal of Climate, 23*(7), 1696–1718. https://doi.org/10.1175/ 2009JCLI2909.1
129. Wario, H. T., Roba, H. G., & Kaufmann, B. (2016). Responding to mobility constraints: Recent shifts in resource use practices and herding strategies in the Borana pastoral system, southern Ethiopia. *Journal of Arid Environments, 127*, 222–234. https://doi.org/10.1016/j.jaridenv.2015.12.005
130. Wingfield, T., Morudu, P., & Kollamparambil, U. (2020). Health shocks, medical insurance and household vulnerability: Evidence from South Africa. *PLoS ONE*, *15*(2), Article e0228034. https://doi.org/10.1371/journal.pone.0228034
131. Worku, M. A. (2024). Spatiotemporal analysis of drought severity using SPI and SPEI: Case study of semi-arid Borana area, southern Ethiopia. *Frontiers in Environmental Science, 12*, 1337190. https://doi.org/10.3389/fenvs.2024.1337190
132. Worku, M. A., Feyisa, G. L., Beketie, K. T., & Garbolino, E. (2022). Rainfall variability and trends in the Borana zone of southern Ethiopia. *Journal of Water and Climate Change*, *13*(8), 3132-3151. https://doi.org/10.2166/wcc.2022.173
133. Yimam, D. A., & Holvoet, N. (2023). Assessing climate change vulnerability of smallholder farmers in northwest Ethiopia: Application of a household intrinsic vulnerability index. *International Journal of Climate Change Strategies and Management, 15*(4), 537–560. http://dx.doi.org/10.1108/IJCCSM-02-2022-0019
134. Yussuf, B. A., & Mohamed, A. A. (2022). Factors influencing household livelihood diversification: The case of Kebri Dahar District, Korahey Zone of Somali Region, Ethiopia. *Advances in Agriculture, 2022*, Article 7868248. https://doi.org/10.1155/ 2022/7868248
135. Zeleke, T., Beyene, F., Deressa, T., Yousuf, J., & Kebede, T. (2021). Vulnerability of smallholder farmers to climate change-induced shocks in East Hararghe Zone, Ethiopia. *Sustainability, 13*(4), 2162. https://doi.org/10.3390/su13042162
136. Zeleke, T., Beyene, F., Deressa, T., Yousuf, J., & Kebede, T. (2023). Smallholder farmers' perception of climate change and choice of adaptation strategies in East Hararghe Zone, Eastern Ethiopia. *International Journal of Climate Change Strategies and Management, 15*(4), 515–536. https://doi.org/10.1108/IJCCSM-01-2022-0014`