IMPACTS OF CLIMATE VARIABILITY AND CHANGE ON CROP PRODUCTION AND ADAPTATION OPTIONS OF SMALLHOLDER FARMERS IN EMBA ALAJE DISTRICT, SOUTHERN TIGRAY, ETHIOPIA

WONDOGENET COLLEGE OF FORESTRY AND NATURAL RESOURCES, HAWASSA UNIVERSITY

MSc THESIS

BY

HALEFOM NEGASI DENGEZE

WONDO GENET, ETHIOPIA

JUNE, 2020

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LIST OF ABBREVIATIONS AND ACRONYMS

CAD	Climate Assessment Decade
CSA	Central Statistics Agency
CV	Coefficient of variance
ENMA	Ethiopia National Metrology of Agency
FAO	Food and Agriculture Organizations
FGDs	Focus group Discussions
GDP	Gross Domestic Product
CRGE	Climate Resilience Green Economy
GHGs	Greenhouse gases
GHGEs	Greenhouse gases Emission
HHs	Households
IPCC	Intergovernmental Panel on Climate change
KIIs	Key informant interviews
MNL	Multinomial *Logit*
MoARD	Ministry of Agriculture and Rural Development
MoFED	Ministry of Finance and Economic Development
NAPA	National Automotive Parts Association
NMA	National Metrology of Agency
PASDEP	Plan for accelerated & sustainable development to end poverty
SPSS	Statistical Package for Social Science
UNDP	United nation of framework convention for climate change
UNFCCC	United nation of framework convention for climate change
WMO	World Metrology Organization
WoARD	Wereda office of Agriculture and Rural Development

Title**:** Impacts of climate change and variability on crop production and adaptation options of smallholder farmers in Emba Alaje district, Southern Tigray, Ethiopia

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ABSTRACT

Climate change and variability are worldwide phenomena which could exert adverse impact on agriculture mainly on crop production. The impacts create serious challenges especially in developing countries including Ethiopia. Emba Alaje district, in southern Tigray is among the highly vulnerable areas of Ethiopia. Hence, the objective of this study was to evaluate the trend of climate variability and change as well as their impacts on crop production; as well as identify perceptions and adaptation options used by smallholder farmers' in the area. The study employed stratified random sampling technique and multiple stage sampling procedure to collect qualitative and quantitative data using interview schedule, key informant interviews and focus group discussions. Accordingly, primary data were collected from 365 respondents selected from three kebelles. Secondary data on long term rainfall and temperature were accessed from NMA. The data were analyzed using descriptive statistical methods with the help of SPSS software version 20 and Microsoft Excel. The study results indicated that, long term seasonal and annual rainfalls in the area are variable with decreasing trend, whereas the temperature is significantly increasing. The survey also indicated that crop production declining and becoming highly variable mainly due to the impacts of climate variability and change. However, the negative impacts of climate change varies among crop types/or and varieties depending on drought and pest resistance and growing agro ecology as well as fertility and water holding capacity of the soil. Moreover, the results showed that, most of the farmers perceive the existence of climate change and its effects on crop production. The findings also revealed that changes in crop type/or and variety along with proper soil and water conservation are the most important climate change adaptation options practiced in the area, despite some respondents are not still practicing any of the adaptation strategies due to limited financial capacity to practice. Education level, age, gender of household head, wealth status, extension service and meteorological information were also influencing the use of one or combination of climate change adaptation strategies. The results revealed that, awareness creation and knowledge generation among the farming community as well as proper financial support to implement suitable adaptation options are vital requirements to reduce the negative impacts of climate change and variability and improve crop productivity. Therefore, it is important to timely establish meteorological stations and generate meteorological advisory services along with credit facilities to enhance crop production in the study area.

Key words: climate change, climate variability, Adaptation options and crop production.

INTRODUCTION

1.1 Back ground information

Climate change is a global occurrence that results in global warming, droughts, flooding that could deplete natural resources (Sejian, 2013). Change in climate is mainly caused due to increase atmospheric concentration of greenhouse gases like carbon dioxide, methane, and nitrous oxide, leading to changes in rainfall pattern, and temperature. The increasing concentrations of GHGs in the atmosphere contributed to the expected increase of the average temperature of the Earth's surface by 1.8 to 4.0°C by the end of the century (IPCC, 2007a).

Although, the direct or indirect impacts of climate variability and change are manifested on all economic sectors to some degree, agriculture is the most sensitive and vulnerable sectors expected to face significant yield losses between 3 and 30 % and extinction of plants and animal species between 15 and 37 % by 2050, unless corrective measures are taken (Nelson *et al*., 2009). Besides that, anthropogenic factors like agriculture and land use change are the major contributors to the prevailing global climate change. The impact of climate change has been assured by several studies and affects the global community causing decrease in the availability of food access, water and other natural resources.

Even though climate change is considered to be a worldwide phenomenon; its impacts are more serious challenge in developing countries including Ethiopia. This is mainly due to their high exposure and socioeconomic vulnerability; and also low adaptive capacity to the effects of climate change. Traditional farming systems with low technological capacity, cannot help to adapt and mitigate severe climate change.The main challenge of climate change on agricultural production is usually related to variations in the rain pattern, and temperature; as well as incidences of floods and droughts that could negatively affect water and land resources.

Ethiopia and other African countries are experiencing long term effects of droughts and food insecurity, especially in the northern Ethiopia in Tigray Region (MoFED, 2006; World Bank, 2009) frequently causing severe land degradation and death of humans and livestock. Tigray is being affected by recurrent drought because of both its arid and semi-arid nature (Deressa *et al*., 2009).

Climate change is the major problem causing food insecurity especially in rainfed crop production. Therefore, effective adaptation practices and risk management strategies should be put to avoid or reduce the serious challenges, since crop production remains being the main source of income for most rural communities of the region, particularly in Emba Alaje district. Adaptation capacity of the agricultural sector to the adverse effects of climate change will be imperative to protect the livelihoods of the poor and ensure food security. Adaptation can greatly reduce climate vulnerability of rural communities by making them better able to adjust to climate variability and change and helping them cope with adverse consequences (Adger *et al*., 2007; Hellmuth, 2007; Bryan *et al*., 2009; IPCC, 2012). Thus, adaptation research has to be enhanced in order to identify appropriate strategies and support the adaptation process through policies guided by scientific evidence.

Thus, improving crop production adaptation strategies through effective support by stakeholders and policymakers needs further attention to reduce the challenges of climate change and ensure food security. It would therefore relevant to gather applicable information on crop cultivation adaptation practices, productivity of crop varieties and extent of climate variability and change. The effective application of adaptation strategies of crop production for improving productivity still lacks better understanding and skill on climate change adaptation options.

1.2 Statement of Problem

Almost 85% of the peoples' livelihood in Ethiopia is directly dependent on the agriculture as income sources, while crop cultivation is still mainly dependent on rainfed production system. The climate of Emba Alaje district which located in the Southern Tigray is characterized by dry semi-arid with erratic and scant rainfall resulting in vulnerability to moisture stress conditions, which created serious challenge to the cultivation of major crops in the area including wheat, barley, pulses, and some sorghum and tef that affected food security and livestock fodder.

However, the impact of climate variability and change on crop production and productivity of cultivated crops in Emba Alaje district has not yet been properly studied. Therefore, the aim of this study was to address the gap of understanding and identify effective crop cultivation adaptation strategies in order to reduce the negative impacts of climate variability and change in the study area.

1.3 Objectives of the study

The general objective of the study were to assess the impacts of climate change and variability on crop production; and identify adaptation options used by smallholder farmers' in Emba Alaje district, Southern Tigray, Ethiopia. The specific research objectives were:

- To evaluate long term climatic variability and trends especially rainfall and temperature in the study area;
- To assess the impacts of climate variability and change on crop production in the study area;
- To assess smallholder farmers' perceptions on climate variability and change and identify barriers for successful adaptation on crop production in the study area;
- To identify smallholder farmers' adaptation options and determinant factors that influences their choice.

1.4 Research Questions

In order to address the above objective, the research questions for this study are as follow:

- How is the long term trend of rainfall and temperature in the study area?
- How is the long term impacts and relationship of climate variability and change on crop production in the study area?
- How is the long term trend of crop production in the area?
- How adapted the study area for rainfed crop production and have changes in rainfall and temperature affected this suitability?
- What adapting strategies are used by smallholder farmers to improve crop productions under climate variability and change?
- What are the constraints faced by farmers to adapt to climate variability and change on crop production?

1.5 Hypotheses

- There is real climate variability and change in the study area.

- There is impact of climate variability and change to reduce production and productivity of major crops in the area.
- There is some perception of smallholder farmers on climate variability and change; and its impacts on rainfed crop production.
- There is indigenous adaptation options used by smallholder farmers’ to improve production and productivity of the study area.

1.6 Significance of the study area

The findings of this study provides basic information about existing production and productivity of rainfed crops, and notify policy makers and stakeholders about the role of climate smart practices as climate variability and change adaptation strategies to improve crop productions is necessarily in Emba Alaje district, southern Tigray, Ethiopia. Moreover, the findings of this study may help in conserving, improving, managing and strengthening the existing adaptation strategies in the study area and expansion of the best practice to the other areas. It also provides organized document for researchers, decision makers, government and nongovernmental organizations and other concerned bodies actions to climate variability and change adaptation strategies. Finally, this study may create land better conditions for crop productions under climate variability and change condition through improved and effective adaptation strategies in the area.

2. LITERATURE REVIEWS

2.1 Definitions and conceptual terms of climate change

The World Meteorological Organization (WMO 2016) explains climate as the "average weather," which is represented the accumulation of daily and seasonal weather events such as temperature, precipitation over a period of time, ranging from months to thousands or millions of years". Weather "is a conditions of the atmosphere at particular time and place over a short period of time" (WMO 2016). According to IPCC (2014), climate change is "a change of climate which is caused directly or indirectly to human activity that changes the composition of the global atmosphere and which is in addition to natural climate variability happened over comparable time periods. Climate variability refers to "variations in the mean condition and other statistical results such as standard deviations and statistics of extremes of the climate on all temporal and spatial scales further than that of individual weather events".

Climate change is the main global problems posing challenges to sustainable livelihoods, food security and economic development, particularly for developing countries (Kibassa, 2013). Climate change, whether determined by natural or human forcing, can lead to changes in the likelihood of the occurrence or strength of extreme weather and climate events or both (Cubasch *et al*., 2013). Recent climate changes have had extensive impacts on human and natural systems (IPCC, 2014a). Increase in population size, economic activity, lifestyle, energy use, land use patterns, technology and climate policy had been the mainly drivers of anthropogenic activities for greenhouse gases emission. According to the report of the IPCC (2014b), the continued emission of greenhouse gases (GHGEs) will cause further warming and long-lasting changes in all events of the climate system, increasing the probability of severe, pervasive and irreversible impacts for people and ecosystems. Moreover, future climate will depend on committed warming caused by past anthropogenic emissions, as well as future anthropogenic emissions and natural climate variability.

2.2 Causes of climate changes

Climate change happens because of internal variability within the climate system and external factors. The external factors are natural and/or human induced anthropogenic activities. Anthropogenic activities cause climate change mainly fossil fuel burning and deforestation and forest degradation for additional agricultural land use (Lovejoy and Hannah, 2005). These contribute to climate change by emitted greenhouse gases, aerosols (small particles), and cloudiness that increase earth's atmospheric concentration (IPCC, 2007). At worldwide, the main source of greenhouse gas (GHG) emissions is from carbon dioxide (70%), primarily from burning of fossil fuel imported from developed countries, while the other sources for GHG are methane and nitrous oxide caused due to deforestation and agricultural activities, particularly the use of synthetic chemicals (Yohannes and Mebratu, 2009).

According to the latest assessment report by IPCC (2013), states with 95% confidence that human influence is the main cause of climate change and that continued emissions of greenhouse gases (GHGs) will cause further warming and changes in the components of the climate system. The emissions of greenhouse gases are predominantly from industrialized countries while the negative effects of climate change are mainly in low income or developing countries. Generally, climate change is expected to affect developing countries more than industrialized countries, because developing countries are less capacity to mitigate and/or adapt to climate changes due to their poverty and high dependence on the environment for subsistence (UNDP, 2007).

2.3 Climate systems in Ethiopia

In general, the major weather systems that cause rainfall are Sub Tropical Jet (STJ), Inter Tropical Convergence Zone (ITCZ), Red Sea Convergence Zone (RSCZ), Tropical Easterly Jet (TEJ) and Somalia Jet in Ethiopia (Seifu, 2004). Similarly, the other sources also indicated that STJ, ITCZ, RSCZ, TEJ and the Somalia Jet influence region A of the country; ITCZ along with some of those which influence region ‘A’ cause rain in region ‘B’; the ITCZ causes rain in region ‘C’ (Figure.1). The rainfall amount and its variability in each of these regions are relatively different. This is mostly related with the movement and/or position of rain causing systems with reference to a given region in different seasons and graphic conditions.

2.3.1 General rainfall pattern in Ethiopia

Season is meteorologically defined as a period when the air mass characterized with homogeneous weather elements such as temperature, relative humidity, wind, rainfall etc; dominate a region or part of a country (NMSA, 1996). The seasons and rainfall regimes are classified based on mean annual and mean monthly rainfall distribution in Ethiopia. There are three major rainfall regimes in the country (Figure. 1) and defined as: Mono-Modal (Single maxima), Bi-modal type-1 (Quasi-double maxima) and Bi-modal type-2 (Double maxima).

1. Mono modal rainfall pattern

The area is dominated with single maxima rainfall pattern as region ‘B’ (Figure. 1). However, the wet period decreases from about ten months in the south west to only about four month in the north region ‘B’.

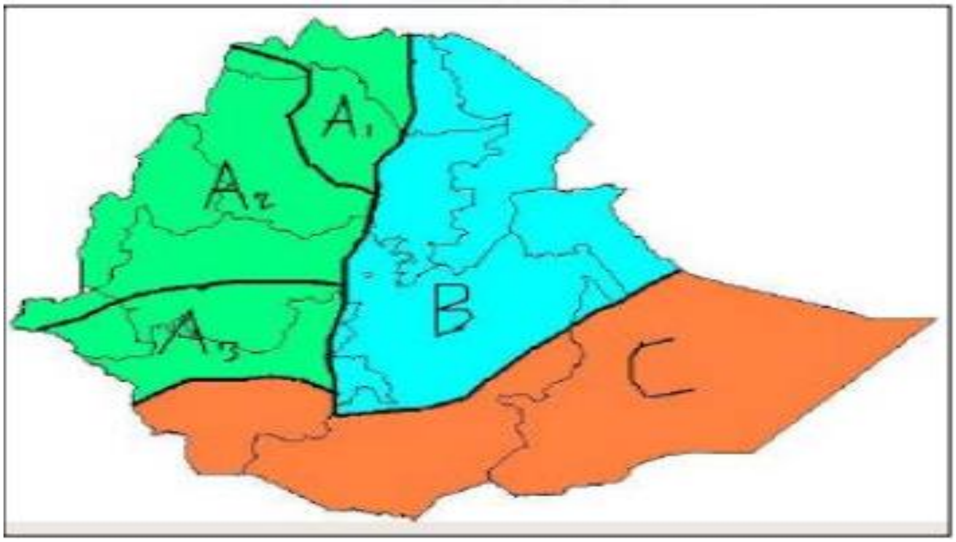

Figure 1: Rainfall Regimes of Ethiopia (NMSA, 2007)

Thus, region-B is sub-divided into three parts designated as b1, b2 and b3, where the wet season moves from February/March to October/November, April/May to October/November and from June/July to August/September, respectively. This part of the Ethiopia is likely to suffer more from climate change risks as possibilities for another because adapting options is limited.

2. Bi-modal type-one

The area is characterized by quasi-double maxima rainfall pattern, with a minimum peak in April and maximum peak in August as allocated in region 'A' (Figure.1). The central and most of the eastern half of the Ethiopia is grouped in this rainfall regime. The two rainy seasons are locally known as summer (June to September) and '*Belg*' (February to May), which are the long and short rainy seasons, respectively. The short dry period of the year (i.e. October to January), which covers the rest season, is known as winter. From these rainfall patterns the *Belg* season is highly characterized by erratic rainfall and in severe cases total failure of the rain.

3. Bi-modal type-two

The area allocated as region 'C' dominated by double maxima rainfall pattern with peak during April and October months. The southern and the southeastern parts of country are grouped in this rainfall regime. The two rainy seasons are from March to May and from September to November. However, the two dry periods are from June to August and from December to February.

2.4 Weather system in Ethiopia

In Ethiopia the weather system that causes rainfall for each season is well described by the (NMSA, 1996) as described below. The country is predominantly falls under the influence of warm and cool Northeasterly winds during winter (dry season). These dry air masses started either from the Saharan anticyclone or from the ridge of high pressure extending into Arabia over Central Asia (Siberia). However, northeasterly winds get interrupted when migratory low pressure system starting in the Mediterranean area move to eastwards and interact with the equatorial/tropical system very occasionally, resulting rainfall over parts of central Ethiopia.

The *Belg,* short rain season coincides with the domination of the Arabian high pressure due to, it moves towards the north Arabian Sea. Main systems during the season are the development of thermal low over south Sudan. The generation and propagation of disturbance over the Mediterranean, occasionally coupled with Easterly waves; development of high pressure over the Arabian Sea; some of the interaction between mid-latitude depression and tropical systems accompanied by troughs and the subtropical jet; and occasional development of the RSCZ.

During summer (the rainy season) , the airflow is dominated by a zone of convergence in low-pressure systems accompanied by the oscillatory Inter Tropical Convergence Zone (ITCZ) extending from West Africa through Ethiopia towards India. The main rain producing systems during the summer season are Northward movement of ITCZ; development and persistence of the Arabian and the Sudan thermal low along 20ºN latitude; development of quasi-permanent high pressure systems over south Atlantic and south Indian ocean; development of tropical Easterly Jet (TEJ) and its persistence; and the generation of low level 'Somali Jet' that enhances low-level southwesterly flow.

2.5 Climate change Trends and Impacts on agriculture in Ethiopia

Climatic change and variability's are the types of changes in weather elements (temperature, rainfall) and occurrence of extreme events in frequency and rate that causes the impacts on agricultural production. Climate change and related weather variability's continued posing climate events challenged both in developed and developing countries. Climate variability and change affect the environmental and socioeconomic sectors, including water resources, agriculture and food security, human health, global ecosystems and biodiversity. According to IPCC (2014b), Climate change causes agricultural problem; resulting to great risks on food insecurity globally. Changes in precipitation pattern and rising temperatures lead to severe water shortages and/or seasonal flooding; caused shifts in crop growing seasons and changes in the distribution of pest and disease vectors which affects food security.

Ethiopia is one of the most vulnerable developing countries to climate change and variability.The most important environmental climate change allied hazards and problems in Ethiopia include drought, floods, heavy rains, strong winds, frost, high temperatures, lightning, land degradation, overgrazing, deforestation, indoor air pollution and water pollution (NMA, 2007). The potential for a system to frequency and severity adverse impact on agriculture is depends on its capacity to adapt the climate changes. Higher temperatures, and increased rainfall variability reduce crop production and productivity results food insecurity in low income and agriculture based livelihood of communities. Thus, the negative impact of climate variability and change is challengeable to countries including Ethiopia that depend on rain-fed agriculture (Edwards Jones *et al*. 2009).

According the past NMA data (1971-2000) that temperature and precipitation from for selected stations in Ethiopia showed the year-to-year variation of rainfall (NMA, 2007). The annual rainfall trend analysis of Ethiopia shows that more or less remained constant when averaged over the whole country while more declining trend has been observed over the Northern and south western Ethiopia (IPCC, 2007).The precipitation is highly variable in amount and distribution across regions and seasons. The seasonal and annual rainfall variability are results of the macro-scale pressure systems and monsoon flows which linked to changes in the pressure systems (Tesfaye, 2003). In Ethiopia the spatial variation of the rainfall is influenced by the changes in the intensity, position, and direction of movement of these rain-producing systems (Temesgen, 2000). Moreover, the spatial distribution of rainfall in Ethiopia is significantly influenced by topography.

The National Metrological Agency (2001) report show that climate variability and change in Ethiopia is mainly manifested through the variability and decreasing trend in rainfall and increasing trend in temperature. Besides, rainfall and temperature patterns show large regional differences. For the IPCC mid-range emission scenario, the mean annual temperature will increase in the range of 0.9-1.1 °C, 1.7 - 2.1 °C and 2.7-3.4 °C by 2030, 2050 and 2080 over Ethiopia compared to the 1961-1990 normal. Chronological climate analysis for Ethiopia indicates that mean annual temperature has increased by 1.3°C between 1960 and 2006, an average rate of 0.28°C per decade. Rainfall is historically highly variable and there is no clear trend in the amount of rainfall over time (McSweeney *et al*., 2008 and NAPA, 2007).

The consequence of the long-term climate related changes in precipitation patterns, rainfall variability and temperature has increased the frequency of droughts and seasonal floods increase losses from rain-fed agriculture (NMA, 2007; World Bank, 2010). Because in Ethiopia agricultural sector contribute more than 45% of GDP, 80% to labor force and 85% to foreign exchange earnings which is highly vulnerable to climate change. More than 95% of crop production is rain-fed which has been produced by small holders and subsistent farmers who have less capacity to adaptation of climate variability and change (MoFED, 2006). Ethiopia is vulnerable to climatic change and variability due to its low socioeconomic adaptive capacity, high rate of population growth, lack of institutional capacity and high dependence on climate sensitive rain-fed agriculture (NMA, 2007). However, the impact of climate change on crop production and sector through reducing soil fertility, increasing crop pests and diseases outbreak, aggravating lack of access to input especially improved seeds and lack of institutional capacity to adaptation.

2.5.1 Impact of climate variability and change on crop production

The negative impacts of crop production from increased climate variability can result in lower incomes and food insecurity especially in developing countries. The repeated frequencies of drought occurrences were due to climatic variability and change that largely damaged the natural resources and critical challenge to total crop production. Majority of the author reported the effects of climate change in terms of rainfall variability, increasing temperature, seasonal flooding, drying of water sources and food insecurity (Berhe *et al*., 2016). Climate change impacts are significant, but depend on over regions and crop type. The impact of these trends tends to grow stronger in over time. The direct and indirect impacts of climate variability and change on crop production were caused economic impacts include reductions in income, employment, savings and investments.

Rate of plant growth and development is dependent upon the temperature surrounding specifically range represented by a minimum, maximum, and optimum (Chen C *et al*., 2015). Extreme temperature events may have short-term durations of a few days increases of over 5°C, which is above the normal temperatures (Rahman MH *et al*., 2018). Extreme temperature events occurring during the summer period would have the most dramatic impact on plant productivity. Climate change may alter precipitation, soil water, runoff, and may reduce crop growing season and increase yield loss and could reduce areas suitable for the production of major crops (Saseendaran SA *et al*., 2015). Climate change might challenge the total crop production that is harvested in a farm, region, state, or country in productivity in many areas (Kumar A *et al*., 2014). According to (IPCC 2014b), Climate change challenges agricultural production; resulting to large risks on food insecurity globally. The impacts of climate change and variability on agricultural crop production and productivity influenced through directly and indirectly.

The investigated impacts of climate variability and change in the context of Ethiopia using a Ricardian approach have a significant impact on net crop yield per hectare (Deressa and Hassan, 2009). The reduction in net revenue per hectare by the year 2100 would be greater than the reduction by the year 2050, suggesting that the negative impacts of climate change will increase with time unless this effect is countered through adaptation strategies. However, the impact of climate change is not the same within crop varieties and across agro ecological zones of Ethiopia.

Although, drought for crop production is the major problems caused through declining farm sizes, natural resource degradation and increases in crop pests and disease. Hence, climate variability have impacted seriously in Ethiopia, resulting in increasing agricultural losses and human suffering , which caused critical food insecurity (MathewosHunde, 2004).

Beside, Ethiopia has a diversity of major agro-ecological zones and suitable for the support of diversified agricultural production (Funk *et al*., 2012). World Bank (2010) and NMA (2007) identified a wide range of climate change adaptation strategies implemented by farmers and pastoralists in Ethiopia.

This review fills this gap by investigating how farm households' decision to adapt, that is to implement a set of strategies (e.g., Agro forestry; soil and water conservation) in response to long run changes in key climatic variables such as rainfall, affects crop productivity in Tigray region of Ethiopia.

2.6 Perception aspects of farmers to climate change

Climate change perception is strongly associated to the degree to which climate induced challenges and opportunities affect the farmers' livelihoods, and their responses and adaptation strategies (Adger *et al.*, 2005; Adger *et al*., 2003; Ndamani & Watanabe, 2015). The perception experiences of natural and environmental factors varies individually (Hartig, Kaiser & Bowler, 2001); and also between social groups, geographic locations and seasons of the year. Local communities /men, women, and children do experience different levels of hardship and opportunity in the face of real challenges climate change (Ndamani & Watanabe, 2015). However, misconceptions about climate variability and change and its associated risks may result in no adaptation, so increasing the negative impact of climate change that number of farmers perceived some climatic risk. In various studies that many farmers are aware and do notice long-term changes of rainfall and temperature trends in their daily lives (Debela *et al*., 2015; Ndamani & Watanabe, 2015; Kusakari *et al*., 2014). According to Debela *et al*. (2015) report a large numbers of farmers who perceived the changes in both higher day and night time temperatures; below normal rainfall amounts, short duration and late onset of rainy seasons; and also higher frequency and intensity of extreme weather events in Ethiopia. The degree of farmers' perception on climate change also depends on their exposure levels, resilience and adaptive capacities (Ndamani & Watanabe, 2015).

A large proportion of farmers perceived that they are most vulnerable to changes in the onset of planting season, poor rainfall amount and distribution during the cropping season; increasing temperatures and flooding, which all factors that can lead to reduced production and food insecurity (Ndamani & Watanabe, 2015). The farmers' perception to impacts of climate change drives them to boost their current production by improving adaptation strategies against future adverse impacts from climate change (Makate *et al*., 2017). The variations observed in perceptions of different groups based on gender, age group, community, and livelihood activities in which they are engaged (Kusakari *et al*., 2014). The farmers understanding their future depend on climate factors (Debela et al., 2015). In many cases, also belief systems do affect the community perception of climate change and individual vulnerability (Kusakari *et al*., 2014). The hazards like flooding and/or drought are interpreted as results of the sins of people and disrespect to God (Kusakari *et al*., 2014).

The perception of climate change impact also varies with education and literal levels and access to early warning information, as well as with the action of local extension services (Debela *et al*., 2015). Therefore, a knowledge gap argues that also influencing people's perceptions of climate change (Tegart *et al*., 2012). People perceptions of risks are subjected by a variety of psychological and social aspects: the experience of the individual, length of the touch and emotion, imagery, belief and traditional values (Slovic & Weber, 2013). Thus, it must be considered the farmers' adaptation strategies to environmental and climate change is strongly influenced by perceptions and opinions, as well as belief and social cultural value systems (Arbuckle *et al*., 2015; Makate *et al*., 2017).

2.7 Farmers' adaptation strategies to climate change

Communities made a number of adjustments to their farming practices in order to adapt with the long-term shifts in weather pattern and unfavorable farming conditions. There have been several studies on adaptation strategies to climate variability and change including change in crop variety and livestock breed, conservation agriculture and diversification of farm enterprise were the predominant means by which the farmers adapted to long-term changes in climate. According to the IPCC third Assessment Report, adaptation has the potential to reduce negative impacts of climate change and to improve beneficial impacts (IPCC, 2001). Smallholder farmers must develop their resilience, including adopting appropriate technologies as making the most of traditional knowledge, and diversifying their livelihoods to adapt with current and future climate problems. To enable effective adaptation measures, governments as well as non-government organizations, must consider integrating climate change in their planning and budgeting in all levels of decision making (Mendelsohn, 2000).

In general, farmers judgments on the type of adaptation are often made by individuals and groups within society indicated that they had changed crops varieties and adopted more drought tolerant; pest resistant varieties/breeds and rainwater harvesting. Another strategy that was reported by the farmers was to diversified crop varieties on crop rotation to minimize the risk of suffering from a total crop failure since different crops are affected differently by climatic events. Communities have developed knowledge, skills, technology, institutional arrangements and strategies that are important sources for adapting to long-term climate change. Depend on the type of economic activities and social networks societies can access local coping strategies against climate shocks. These highly differ among households and communities.

Local communities have always adapted to climate variations based on their resources and knowledge accumulated through experience of past weather pattern. The adaptive capacity of household farmers use when faced with climate change could also differ in terms of their local applicable and accessible, gender equity effects, their cost affordable, compatibility with other programs implemented practices (Admassie, 2008).

Climate adaptation actions will need to solve the systemic weaknesses; and also climate variability's and vulnerabilities that have long term negative effects livelihoods of communities. But, climate change will have the challenges to implement current and future development plans; community, national and international adjustments and changes at every level. Thus, a better understanding of the impacts, costs, changes and communities perceptions of climate change, ongoing adaptation measures, and the decision-making process is important to brief policy makers and sector institutions designed at promoting successful adaptation strategies. Ethiopia will need to mitigate the impacts of climate change and adapt to the situation, where possible through climate smart agriculture to address negative impact of climate change on environment and agricultural productivities, where it cannot (Yesuf *et al*, 2008).

The impact climate change and variability will differ regionally; based on the bio-physical and socioeconomic conditions within Ethiopia; and also the management practices of impacts will need to be defined for each region depend on the analysis of current information and practices. The new as well as current technologies used in new ways can support this response, but only if enabling the appropriate institutional and policy instruments is applied to encourage integration and adaptive understanding to take account of ongoing uncertainties or new opportunities (Tadege, 2007).

2.7.1 Climate change adaptation options on crop production

In Ethiopia, climate change leads to an increase of drought frequency and/or duration, but an adaption option for the farmers are to choose crop types or varieties that more drought tolerant and can withstand temperature and water stresses better (Howden *et al*., 2007). Another adaptation strategy is to avoid critical crop growth stages to coincide with periods of harsh climatic stresses. This can be ensured through altering the length of the growing period by varying planting and harvesting dates and/or by changing to crop types with a more appropriate thermal time is an adaptation option (Howden *et al*., 2007). Using crop types with a shorter growing period than the previous crop can be applied in areas where climate change results in an earlier end of the rain period. This strategy will similarly ensure that the new crop is fully matured and thus not in a critical growth period when the period of rain deficit starts.

Irrigation is another method to adapt to changes in precipitation and generally seen as effective method to increase agricultural productivity in rain-fed systems by supplementing rain water during dry periods (Gebrehiwot & van der Veen, 2013).

In Ethiopia the farm households with larger access to social capital are more likely to adopt yield-related adaptation strategies. However, lack of information and shortages of labor, land, and money were identified as major reasons for not adapting. Besides, Temesgen *et al*. (2008b) identified crop diversification, tree planting, soil-water conservation, changing planting dates, and irrigations are common adaptation strategies; but level of education, gender, age, and wealth of the head of household; access to extension and credit; information on climate, social capital, agro ecological settings as main barriers to adapt climate change. According the literature review the following common climate change adaptation strategies are common in Ethiopia.

i. Crop diversification

In Ethiopia, crop diversification strategy is widespread used to avoid problem of total crop failure rather than maximizing yields of one particular crop. It is the most commonly used method to overcome climate changes in Ethiopia. Greater use of different crop varieties in the same season could be associated with lower expenses and ease of access by farmers (Kristiansen, 2011). Legesse B. *et al.* (2018) noted that crop diversification, soil and water conservation and moisture harvesting practices were commonly used climate change adaptation strategies in eastern Ethiopia.

ii. Mixing crop-livestock production

Mixed species herds, splitting animals into discrete herds, and mobility in response to seasonal variation in pasture productivity based on cropping system are key strategies in Ethiopia. Selling of livestock was a common coping strategy during drought periods amongst farmers in the Upper Awash Basin in Ethiopia (NAPA, 2007).

iii. Agro forestry

According to Kristiansen (2011), agro forestry was one of the major methods used by farmers to adapt to climate changes in Ethiopia. Vegetation like trees, plants, and grass are important because the roots protect the soil from erosion. Trees are valuable during floods and droughts, and many trees together might give wind break, a more fresh air, and also shadow.

iv. Soil and water conservation (SWC)

In Ethiopia, farmers have often used different kinds of soil and water conservation strategies since around 1990, and this strategy have probably developed much since that time. Soil and water conservation strategies are mainly used farmers due to soil degradation and soil erosion, and want to rehabilitate their fields. These activities are increasingly important today because climate changes to some extents are accelerating these processes (Kristiansen, 2011).

v. Irrigation and diverting of water

In Ethiopia, since 2003 only 2,900 km^2 or 1% of cultivated land is irrigated (CIA, 2011). Use of irrigation is one of the least practiced adaptation strategies among the major adaptation methods in Ethiopia (Deressa, 2009).

vi. Farmers' response to perceived change temperature and precipitation

In developing countries including Ethiopia, the common approach to studying farmers' perception to climate change is based on comparing farm survey results with data records from meteorological stations. Although, informative in terms of understanding the level of understanding of farmers and the possibility of validating farmers' claims of perceptions of change against meteorological data. However, these approaches do not clearly identify factors influencing awareness of climate change (Deressa *et al*., 2011).

2.8 Climate change response in Ethiopia

Ethiopia had suitably initiatives to reacted climate change, by ratifying significant international conventions and basic steps are being taken to implement the two categories of responses to climate change, mitigation and adaptation. Through this respect, the country briefed the UNFCCC and its associated appliance to the UNFCCC in 2001, and also its first Climate Change National Adaptation Programme of Action (NAPA) in 2007 to the UNFCCC (MoFE, 2015). Therefore, the main interventions are given considered as follow:

- Ethiopia initiated to build carbon neutral economy (CRGE) by 2025.
- The country briefed its Nationally Appropriate Mitigation Actions in 2010.
- Multi-sectoral adaptation plan and other associated approaches are also being prepared.
- The existing national policies and sectoral programs targeted towards environmental rehabilitation and socio-economic development addressed the impacts of climate change either directly or indirectly. In Ethiopia the other response options to climate change are notable as follow:
    - Environmental Conservation policy and strategies of Ethiopia
    - Policy and Strategy on Agriculture and Rural Development

- Sustainable Land Management (SLM)
- Disaster Prevention and Preparedness national policy.
- National Policy on Biodiversity Conservation and Research
- National Plan for Accelerated and Sustainable Development to End Poverty (PASDEP)
- Growth and Transformation Plan (GTP) which is now the second phase is under way.

However, considering the ever increasing threats of climate change, Ethiopia still requires initiative climate change policy to address the complicated severe impacts of climate change.

2.9 Conceptual framework

This study examined climate variability and change impacts on crop production and the adaptation strategies that were adopted by smallholder farmers in Tigray, Ethiopia particularly in southern zone Emba Alaje district. According the Portier *et al.* (2010) report, the conceptual framework shows the study was adapted and it helped as a strategic tool to better understand the interaction between environmental systems, climate change and adaptation strategies (Figure 2). The conceptual framework takes in to consideration the climatic variability theory that links climatic variations to environmental changes. Increasing atmospheric greenhouse gases concentration and other drivers change global climate and alters agricultural productions.

Both the mitigation and adaptation interventions modify the environment and climate change. The predominant impact on agriculture comes through environmental changes as a result of climate change, although there are direct impacts from both climate changes and mitigation/adaptation. The weather patterns and decreased availability of precipitation influence adaptation and mitigation strategies.

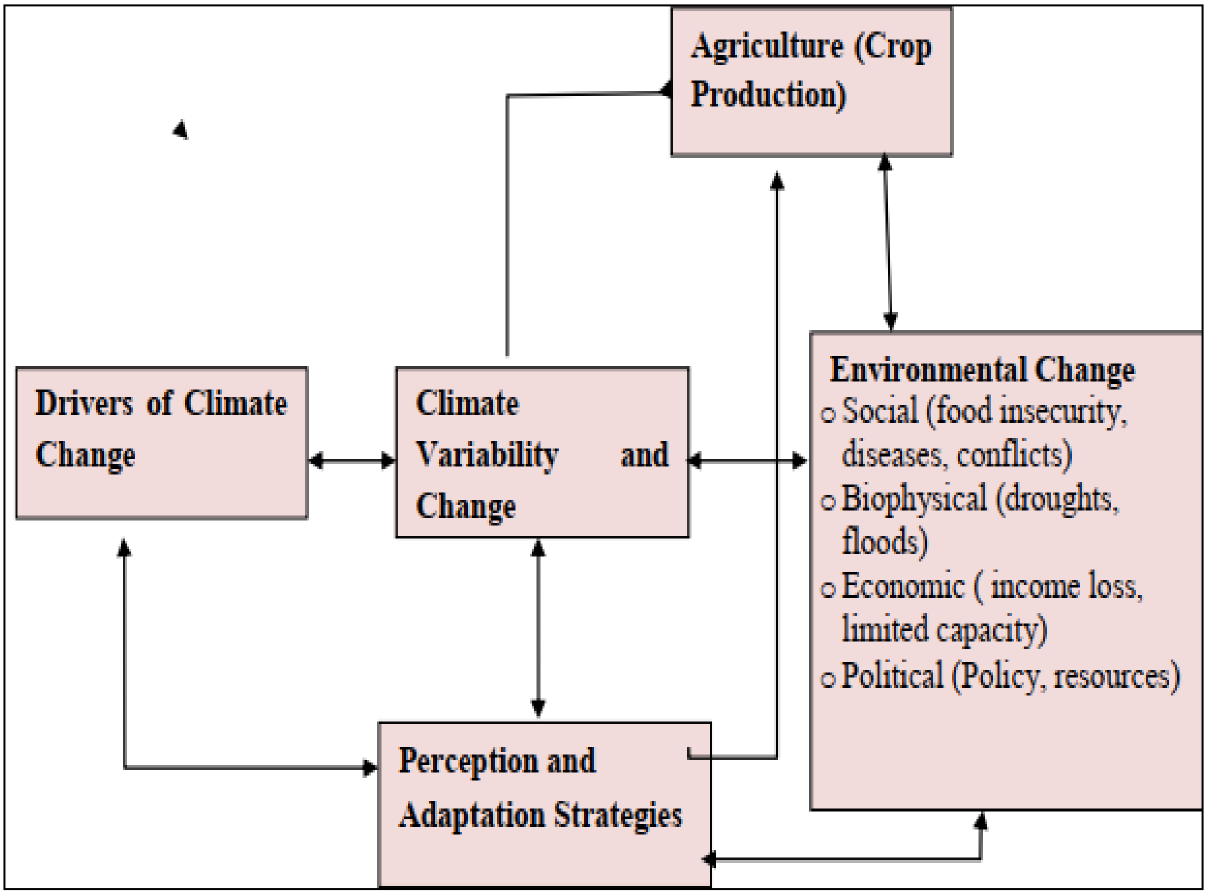

Figure 2: Interaction of Environmental systems, climate Change, Adaptation options

Source: Portier *et al.* (2010).

The physical and socioeconomic environment like social, economic, biophysical and political variations influenced the environmental change. Each factor corresponds to a system that has its own individual driving forces, objectives, and indicators. The biophysical factor focuses on sustaining the resilience and integrity of ecological systems. The economy is geared highly towards improving human welfare, principally through increase in the consumption of goods and services. The social factor gives suitable emphasis to improve human relationship and achievement of individual and group targets. The political domain on the other hand focuses on power, policies and sharing of resources. All the four factors are affected by climate variability and change and balance among these domains are critical to designing effective adaptation and mitigation strategies' to climate change.

Suitable mitigation and adaptation mechanisms affect positively both environmental and climate change, and thereby inducing positive effect on agricultural production. In addition, some adaptation activities directly improve agricultural crop production through intensive inputs and technologies and crop management practices such as crop diversification, crop rotation, soil and water and conservation farm lands.

3. MATERIALS AND METHODS

3.1 Description of study area

This study was undertaken in Southern zone Tigray, Emba Alaje district administrative center of Addishu in the Northern Ethiopia (Figure 3). The district is located at about 35 km south of the zonal capital Maichew and 88 km southeast of the regional city, Mekelle; with geographical coordinate of 39° 15' to 39° 35' E and 12° 00' to 12° 51' N. Emba Alaje district bordered by Hintalo Wegerat district in the north east, Emda Mehoni district in the south, Raya Azebo district in the south east, Seharti Samre district in the north western and Amhara region in the west. The total land area of the study area is about 76, 773.4 ha classified as forest area 10704.7 ha, settlement 10181.25 ha, range land 25690.26 ha; while the cultivated land is 24676.75 ha, out of which 2378.27 ha is irrigated land, comprising a total of 20 rural

Kebeles. The altitude ranges from 1860-3891 m.a.s.l in which the topography is generally classified mostly as sloppy and flat (WoARD, 2019).

The agro ecological zones of the district is classified as lowland <1500 m.a.s.l, midland 1500-2300 m.a.s.l. and highland > 2300 m.a.s.l. The temperature of the area ranges from 14°C and 22°C and the annual rainfall from 585 – 845 mm, with highly erratic and unpredicted pattern as summer rain. The rainfall pattern of the area is bi-modal type in which minor/*belg* season from March to May, main/ summer rainy season is from June to September. The soil type in the study area is dominated by clay loam and sandy loam soil.

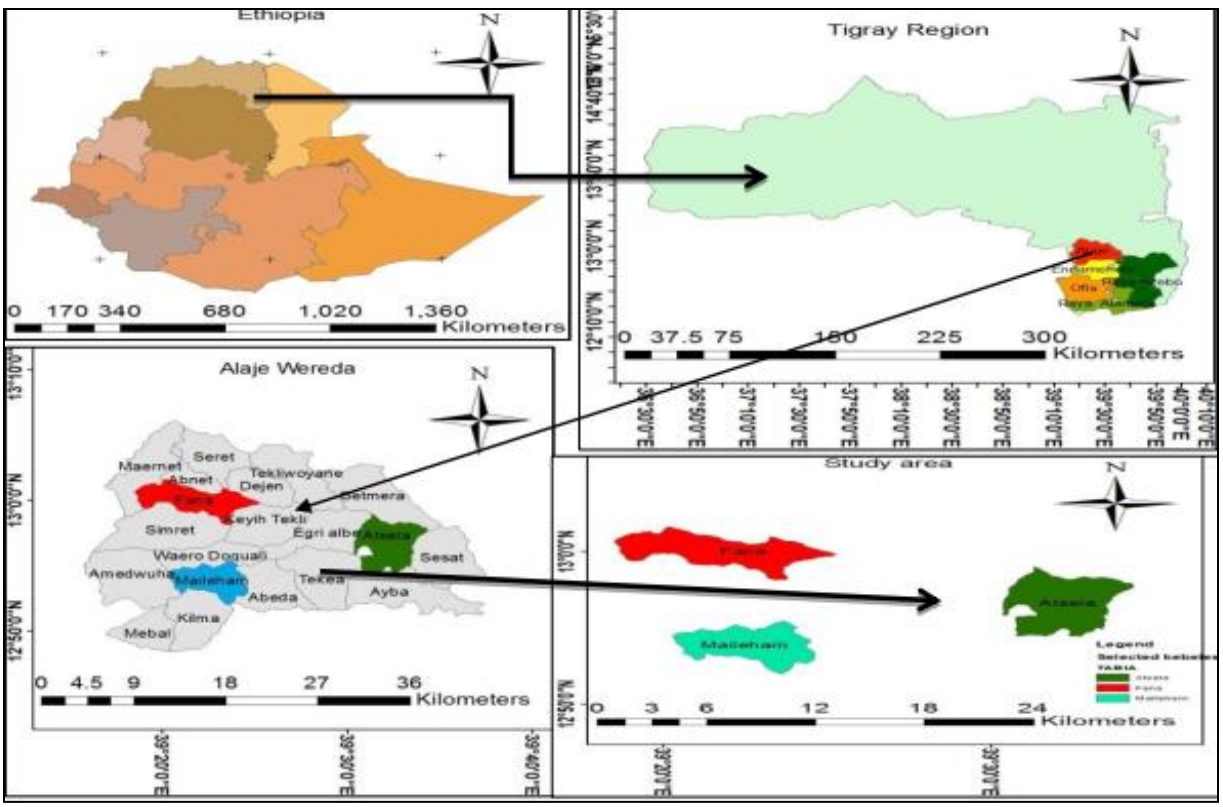

Figure 3: Location Map of the study Area. (Source: Ethiopian mapping Agency)

The district has total population of 131,207 of which, 48.66% are males and 51.34% are females in 2007 census. The total number of households in the district is 28,524 in which

21,678 are male and 6,846 are female headed (WoARD, 2019). Similar to other parts of Ethiopia, agriculture is the dominant activity of the rural communities in the study area which includes crop cultivation such as; wheat, barley, beans, sorghum and tef along with livestock farming on 0.25 - 0.5 ha average land holding of the smallholder farmers. The vegetation cover includes grasslands, shrub lands, woodlands, and cactus closed areas (WoARD, 2019).

3.3 Sampling techniques and procedure

This study employed stratified random sampling technique and multiple stage sampling procedure to collect data for the study site. In the first stage; Emba Alaje district was selected purposively because it is one of the most climate variable and change affected area in the southern Tigray zone of Ethiopia. In the second stage, 20 peasant association kebeles were stratified into three agro-climatic zones (highland, midland and lowland). Then in the third stage, out of the total 20 peasant association kebeles, three kebelles; Atsela from highland, Fana from midland and Maileham from the lowland agro-ecological zones were selected purposively based on their climate variability and change impacts and agricultural crop adaptation strategies. In the fourth stage, a list of 365 farm household heads was obtained randomly selected from the three kebelles by the district's agricultural office.

The sample size for the study was determined through the mathematical formula used by Yamane (1967), to calculate the sample size, at 95 per cent confidence level and p= 0.05 are assumed for this equation as follows:

$$n = \frac{N}{1+(N*e^2)}$$

Where: n = Sample size, N= Total household heads (population), e = expected sampling Error.

Therefore,

$$n = \frac{N}{1+(N*e^2)} = \frac{4203}{1+(4203)(0.05)(0.05)} = 365$$

Out of the total of 365 selected households, 124 households from the highland (Atsela), 142 households from midland (Fana) and 99 households from the lowland (Maileham) agro-ecological zones based on proportional population number of households 4,203 available in the three selected kebeles. Both open ended and closed questions were developed for interview with a semi-structured questionnaire.

3.4 Data collection methods

Trained enumerators were used in the collection of the primary data. To gather the required information, different data collection instruments were implemented. The primary data included; climate trend and its impact on rainfed crop production; and agronomic adaptation strategies by using semi-structured interview, as well as scheduled three focus group discussions (FGDs) were conducted to cross check the information obtained from the household survey in the selected kebelles. Eight to twelve members were considered for the FGD from each selected kebeles and both sex groups focusing on those who lived more than twenty years in the study area. Their education status ranged from illiterate or informal/religious to secondary education and the age variation from 26 to 80 years. Key informant interview (KII) was also conducted with eighteen different individuals by including; three development agents, three local leaders, three model farmers from each sample kebelles and nine Agriculture and Rural Development experts.

Secondary data such as temperature and rainfall were collected from 1989-2018 from Ethiopia National Meteorology Agency (NMA) records. Additionally, the assessed annual major crop production for wheat, barley, tef, sorghum, and beans data were collected from CSA and the agricultural office of the district undertaken for the period 2007/8-2018/19. The discrepancy of applying a standardized period within the data sets is attributed to gaps in the crop production data. To this extent, the period between 2007/8 and 2018/19, spanning twelve years of climate data and crop production relationship and trends, was carefully used. The two data sets were focused to bivariate correlation and statistical analysis to identify the impact of climate variability and change on crop production. After summarizing all the information obtains through the above techniques was used as a basis to design the questionnaire checklist. The discussions were conducted first with the farmers and then with the extension experts and development agents. These data were used to evaluate long term climatic trends especially rainfall and temperature; assess the long term impacts and relationship on crop production; and identify smallholder farmers' adaptation strategies in the study area.

3.5 Data analysis

Quantitative and qualitative data obtained from survey were analyzed using descriptive statistical methods such as frequencies, percentages, tables and graph with the help of Statistical Package for Social Science (SPSS) software version 20 and Microsoft Excel. Descriptive statistics such as mean, frequency of occurrences and percentage were computed to summarize rainfall and temperature change and crop production trends; and also adaptation strategies used by farmers.

For this study, long term trends and relationship of climate mainly temperature and precipitation with crop production; and also adaptation strategies was used to generate statistical indices generated as follows:

Regression analysis was employed to evaluate long term rainfall and temperature trends/ changes. The regression equation that describes a simple linear type regression relationship in a population is expressed as:

$$\mathbf{Yi = \alpha + \beta\ Xi + \varepsilon i} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(1)}$$

Where: 'Yi' dependent variable (rainfall and temperature),'α' Population Y-Intercept, 'β' Population Slope, 'Xi' independent variable (time series), 'εi' random error

Coefficient of determination (R^2) value which shows the degree of relationship between dependent (Y) variable (rainfall and temperature) and the independent time series (X), using the following equation:

$$\boldsymbol{R^2} = \frac{\left(\sum \boldsymbol{XY} - \frac{\sum \boldsymbol{X} \sum \boldsymbol{Y}}{\boldsymbol{n}}\right)^{\mathbf{2}}}{\left(\sum \boldsymbol{X^2} - \frac{(\sum \boldsymbol{X})^2}{\boldsymbol{n}}\right)\left(\sum \boldsymbol{Y^2} - \frac{(\sum \boldsymbol{Y})^2}{\boldsymbol{n}}\right)} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (\mathbf{2})$$

To understand the current relationships of rainfall and crop production, the Pearson product moment correlation Coefficient of variability (CV) was used calculated to estimate the extent of variability especially in annual and seasonal rainfall.

$$CV = \frac{\sigma}{\mu} * 100 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots .. \ldots \ldots \ldots (3)$$

Where: ‘CV’ is the coefficient of variation; μ is the average long-term rainfall over the given decade; ‘σ’ is the standard deviation of the decadal rainfall.

The Standard Precipitation Index (SPI) also used to quantify the precipitation deficit for a given calls as follows:

$$SPI = \frac{Xi - \overline{X}}{\sigma} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (4)$$

SPI refers rainfall anomaly (irregularity) on multiple time scale; ‘X_i’ annual rainfall in year i; $\overline{X}$ is long-term average rainfall and ‘σ’ is represented the standard deviation over the period of observation (Woldeamlak, 2009). Hence, the drought severity classes are: extreme drought (SPI < -1.65); severe drought (-1.28 > SPI > -1.65); moderate drought (-0.84 > SPI > -1.28); and no drought (SPI > -0.84).

Multinomial *logi*t model was used to identify determinant factors that influence the selection and implementation of adaptation strategies by the famers as follows:

$$\boldsymbol{P\left(y = \frac{j}{x}\right) = \frac{exp(x\beta j)}{\left[1 + \sum_{h-1}^{j} exp(x\beta h),\ \ j = 1..,J\right]}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (\mathbf{5})$$

Where: ‘P’ stands for probability, ‘J’ stands for adaptation options, ‘X’ for explanatory variables and β_j = K x 1 is coefficients j = 1, 2.., J.

The dependent and independent variables for the above model in assessing impact and relationship of climate change on major crop productions are assumed to be a function of farm household characteristics, time series, adaptation strategies, climate factors (temperature, rainfall), production factors and agro-ecological settings (highland, midland, lowland).

4. RESULTS AND DISCUSSION

4.1. Demographic and socioeconomic characteristics of the respondents

The study result indicates that, 70.7% of the respondents were male. With regard to age, about 64.7% of respondents were between 35-65 years old that is, in a productive age group (Table. 1). This indicates that, such number of people has the ability to take risk against climate variability and change impacts. Saris *et al*., (2006) revealed that household (HH) members of less than 15 and greater than 65 years of age are not within the active labor group, mainly unattributed by the physical fitness and ability to take risk.

As depicted in Table. 1, the result of the survey indicates that, 76.4% of the respondents are married. In line with this, more practices of agriculture were carried out by married people to feed their children (Deressa *et al*., 2008). The educational status of the total respondents' shows that, 56.4% of them did not attended primary and secondary schools. This would probably make them less sensible for decision and adoption of new changes with regard to the farming activities. Classified by asset endowments 16.2% of farm households are rich, 50.4% medium and 33.4% are poor. FGDs and key informants revealed that smallholder farmers have access to irrigation, fertile soil and better landholding resources seem to have contributed to better wealth status.

Table 1: Demographic and Socio-economic characteristics of the respondents (n=365)

Variables		Frequency	Percentage (%)
Sex of HH head	Male	258	70.7
	Female	107	29.3
Age of HH head in years	Less than 35	102	27.9
	35-65	236	64.7
	above 65	27	7.4
Marital Status of HH heads	Married	279	76.4
	Single	49	13.4
	Divorced	33	9
	Widow	4	1.1
Wealth status of HH heads*	Poor	122	33.4
	Medium	184	50.4
	Rich	59	16.2
Educational status of HH head	Illiterate	206	56.4
	Primary	115	31.5
	Junior	39	10.7
	Secondary	5	1.4
Land holding size in ha	less than 0.25	47	12.9
	0.25-0.50	269	73.7
	0.51-0.75	22	6.0
	0.76-1.0	24	6.6
	greater than 1.0	3	0.8
Farming system	Rain fed farming	318	87.1
	Irrigated farming	30	8.2
	Others	17	4.7
Farming experiences in years	< 5	20	5.5
	5-10	45	12.3
	11-15	51	14
	16-20	49	13.4
	> 20	200	54.8

Regarding the land holding status, about 73.7% of the HHs have 0.25- 0.5 ha of farm land. Bradshaw *et al*. (2004) reported that farm size status has both negative and positive effects on decision of the adaptation options, although the effect of farm size on technology adaptation is inconclusive. The survey result indicated that, 87.1% of the respondents in the study area were practicing rainfed farming system (Table.1), which is the most vulnerable to climate variability and change impacts. According to the study of Pettengell (2010) communities which depend on rainfed crop production are particularly more vulnerable to climate variability and change due to the climate sensitive nature of their activities.

Regarding farming experience, 54.8% of the sample respondents had more than 20 years of crop production experience. More experienced farmers may have improved information to evaluate the impacts of climate variability and change on crop production as well as implement the effective adaptation strategies.

Assessment of the profile of the respondent households in the study Kebeles revealed that their socioeconomic set up is highly vulnerable to climate change and weak as a substantial number of the respondents are lacking adequate resources that are needed to adapt the negative impact climate change on crop production. The prevalence of resource poor and subsistence farmers need to design climate adaptation strategies which could enable this segment of the community to increase crop production and productivity.

Although literacy plays vital role in enhancing climate change adaptation of improved and new technologies, most (56.4%) farmers had not completed primary level which would have negative implication in adaptations on improved agriculture crop production activities. Whereas farmers in the study area are in short of sufficient farm land and even landlessness among the young population is in the increasing trend mainly due to the presence of high fertility rate. Small plot of land coupled with climate variability has made the agricultural system in the study area more challenging. As a result, poor family planning practices and climate change adaptation strategies to reduce negative impacts of climate variability and change could worsen the challenges in the study. This would increase the number of food insecure months that farmers would face in the future, unless irrigation farming system come into action.

Farmers in the study areas, have clear perception and farming experiences on the drastic change in land use that could be taken as a good opportunity of averting the negative consequences of climate change. Consequently, selecting crop varieties and soil and water conservation have become common practices in crop production to cop up with the existing moisture stress in the study area.

4.2 Farmers' perceptions on climate variability and change

Developing a good understanding of the socioeconomic settings in the context of climate trends of change and how farmers perceive climate change patterns is an integral component in the process of addressing climate change issues. Therefore, assessment of the perception of farmers on climate change trends and comparing with the empirical evidences of long term climate data would also provide insights how perception of climate change influences motivation of farmers to pursue adaptation measures on climate change.

The household survey regarding the perceptions and experience of climate variability and change impacts by stallholder farmers in the different agro-ecological zones, sex and age of household heads showed important results in Emba Alaje district (Table. 2). In addition, the focus group discussions and key informant interviews showed that, the rainfall in the study area is unpredictable with a shorter duration caused by late onset and early cessation in both small and main rainy seasons has been affecting crop production in the last thirty years.

According to the household survey, about 95% of the respondents perceived the occurrence of, long-term climate variability and change, whereas the remaining only 5% did not perceive any change in climate in the study area (Table. 2). With respect to temperature about 66.85% of the respondents reported an increasing trend in temperature especially in highlands of the study area, in which the temperature had been increasing, where as 6.85% perceived rather the temperature has been decreasing. However, 6.57% of the households had no idea, while 19.72% of respondents perceived that the temperature remained constant.

Table 2: Farmers' perceptions on climate change and variability at various agro ecological zones of Emba Alaje distric in Tigray Region (n=365)

Current Climate variability and Change		Percent (%) of perceptions at kebelle level			
		Atsela /Highland/	Fana /Midland/	Maileham /Lowland/	Total
Temperature level	increasing	72.58	63.38	64.64	66.85
	decreasing	4.83	10.56	4.04	6.85
	The same	17.74	18.30	24.24	19.72
	Do not know	4.83	7.74	7.07	6.57
Total		100	100	100	100
Rainfall amount	Increasing	8.06	8.45	4.04	7.12
	decreasing	77.42	81.69	88.89	82.19
	the same	12.90	7.74	5.05	8.76
	do not know	1.61	2.11	2.02	1.92
Total		100	100	100	100

Likewise, about 82.2% of households perceived that the rainfall amount is declining, while 7.12% perceived increasing. However, 1.92% of the households had no idea about it, and

8.76% of respondents perceived that the rainfall amount remained constant. In general, the predominant climate related changes perceived by smallholder farmers showed an increase in temperature but decreases in rainfall in the study area. In addition to their perception, household farmers indicated their various sources of climate information. Formal communication with government focal agents as a source of information is mentioned by more than 62% of the respondents, while the role of nongovernment organizations and the mass media were underscored as well. Informal communication among the farmers themselves is also reported as an important source of information about climate change and its impacts (Table. 3).

Table 3: Primary sources of information for the farming households on climate change and its impacts in Emba Alaje distric of Tigray Region

Source of information	Number of respondents	Percentage (%)
Government focal agents	226	62.00
Local elders	25	6.85
Radio/TV	51	14.00
NGO	16	4.38
Own understanding	27	7.40
From other farmers	20	5.47
Total	365	100

4.3. Climate variability and change of Emba Alaje district (1989-2018)

4.3.1 Annual and seasonal rainfall variability and trend

Long term annual, seasonal and monthly rainfall data were accessed from NMA Maichew station for the duration of 1989-2018 to evaluate the pattern and variability. The three data sets, described as Climate Assessment Decade (CAD), of 10 years, ranging from 1989 to

1998, 1999 to 2008, and 2009 to 2018, were categorized to allow comparison of variation in rainfall distribution in the study area. According the analysis results, the seasonal rainfall of Emba Alaje district southern zone Tigray, generally shows a bimodal rainfall pattern, and CAD for each data set is further grouped into summer (main) rain season, between June-September, and *belg* (minor) rainy season, between Marc - May. This grouping was intended to examine the comparative basis for the extent of variability. The major season for the first decade under consideration (1989-1998) recorded an average rainfall of 456.32 mm, the second decade (1999-2008) which recorded 491.06 mm and the third decade (2009-2018) 411.07 mm which was significantly lower rainfall compared to the second and first decade. Similarly, the minor season for each CAD recorded 250.37 mm, 141.35 mm, and 142.42 mm for 1989-1998, 1999-2008, and 2009-2018, respectively, with the highest incidence of variability and declined rainfall of the period under consideration. In general, the result shows a decreasing trend and variability in distribution in both the annual and seasonal (major and minor) rainfall amount over the last 30-year period in the study area (Table 4).

The statistical analysis also revealed a higher coefficient of variation in seasonal rainfall amounts rather than annual coefficient of variation for the study area (Table 4). Especially, the coefficient of variation (48.97%) of the *belg* rainfall indicates that, there was very high inter variability which makes it unreliable for crop production agricultural purpose. Conversely, variability of the annual rainfall (16.68%) indicates, the existence of seasonal shifts of rainfall in which the unpredictable and less productive offseason rains are stabilizing the annual rainfall inconsistency.

Table 4: Coefficient of values of total annual, summer and *Belg* RF in Emba Alaje district (1989-2018)

Rainfall	Minimum	Maximum	Mean	Std. Deviation	CV (%)	R-value	Slope	R^2-value
Annual	478.0	1015.0	770.50	128.54	16.68	-0.491^{**}	-7.175	0.241
Summer	220.0	716.0	452.90	119.52	26.39	-0.096	-1.297	0.009
Belg	31.0	412.0	198.10	96.17	48.97	-0.490^{**}	-5.357	0.240

According to the National Meteorological Agency of Ethiopia (NMA 2007), a rainfall amount with a CV% less than 20 is less variable, that with a CV% between 20 and 30 is moderately variable, and that with a CV% greater than 30 is highly variable. More over the probably drought occurs is much higher when the negative anomaly from the mean seasonal rainfall is 19% or more. On the other hand the 26.4% CV value of the summer rainfall shows that summer rainfall was relatively less variable than *belg* rainfall and hence crop production is possible although the reliability is still less. Generally both the summer and especially the *belg* rainfalls are variable that could negatively affect crop production in the study area unless supported by supplementary irrigation.

The results of statistical correlation and regression rainfall trend analysis also indicated a decreasing rainfall trend in study area (Table. 4). Significance test for the regression trend is of paramount importance in order to predict the likely impacts of climate change. Accordingly, the results of the annual and *belg* rainfall analysis showed statistically significant and negative correlation with time series with r-values of -0.491^{**} and -0.490^{**} respectively (Table. 4). The regression statistics analysis also confirmed that, the annual, summer and *belg* rainfalls are expected to decrease by 7.175 and 5.357 mm respectively for each year between 1989 and 2018 years in the study area (Figure. 4).

The decreasing trend in the bi-modal rainy seasons coupled with the higher rainfall variability especially during the *belg* season, has forced farmers to produce crops only during summer season. The impact of rainfall on crop production can be related to its total seasonal amount or its intra seasonal distributions.

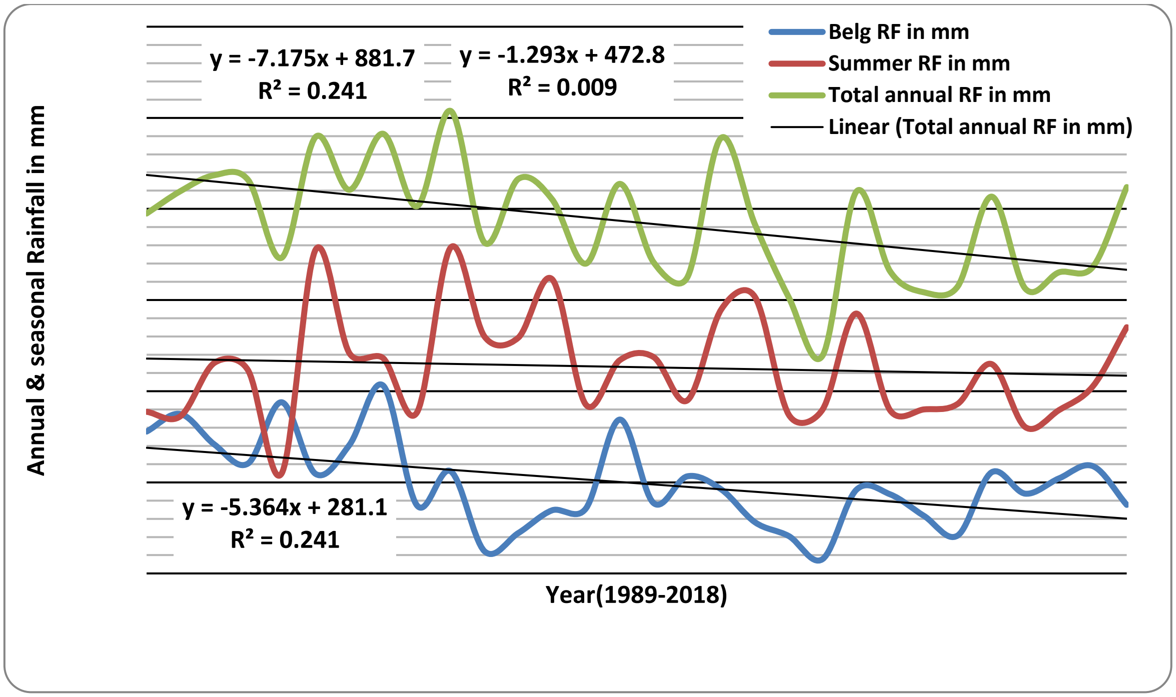

Figure 4: Annual rainfall trend of Emba Alaje District (1989-2018)

Source: NMA, Maichew Station, Tigray, Ethiopia

Standardized precipitation index (SPI) analysis:

Among the 30 years annual rainfall data analysis, 14 years (46.67%) recorded below the long-term annual average, in which most of them were the during last decade, while 16 years (53.33%) years recorded above average (Figure 5). About 84.6% of the years with positive SPI values occurred within the period until 2001, while 70.6% of the years with negative SPI values occurred from 2002 to 2018 indicating that drought frequency is increasing within the last two decades.

Similarly, the drought assessment report of Woldeamlak (2009), expressed that, there were seven drought years in the period spanning from 1998 to 2018 in the study area. The 2009 rainfall amount was the lowest SPI record (-2.28) and extreme drought in the observation period, while there were six moderate drought years (2005, 2008, 2011, 2012, 2013, 2015 and 2016) with the SPI values -0.94, -1.28, -0.84, -1.19, -1.09, 1.13 and -0.85 respectively, which account 23.3% of the total number of observation years. In contrast, the SPI values of the rest 2006, 2007, 2010, 2014, 2017 and 2018 years didn't show drought period, although their negative values indicate dryness (Figure. 5).

The wettest years 1.44 in 1998, 1996, 1994 and 2006 with SPI values of 1.90, 1.51 and 1.46 respectively, may be associated with the probability of flood incidences in the study area (Figure. 5). The SPI result indicates that long-term drought characteristic in the study area shows the challenging extent on crop production by climate variability and change. Similarly, studies in Ethiopia show that, the frequency and spatial coverage of droughts have increased over the past few decades (Woldeamlak *et al*.,2009; Lautez *et al*., 2003).

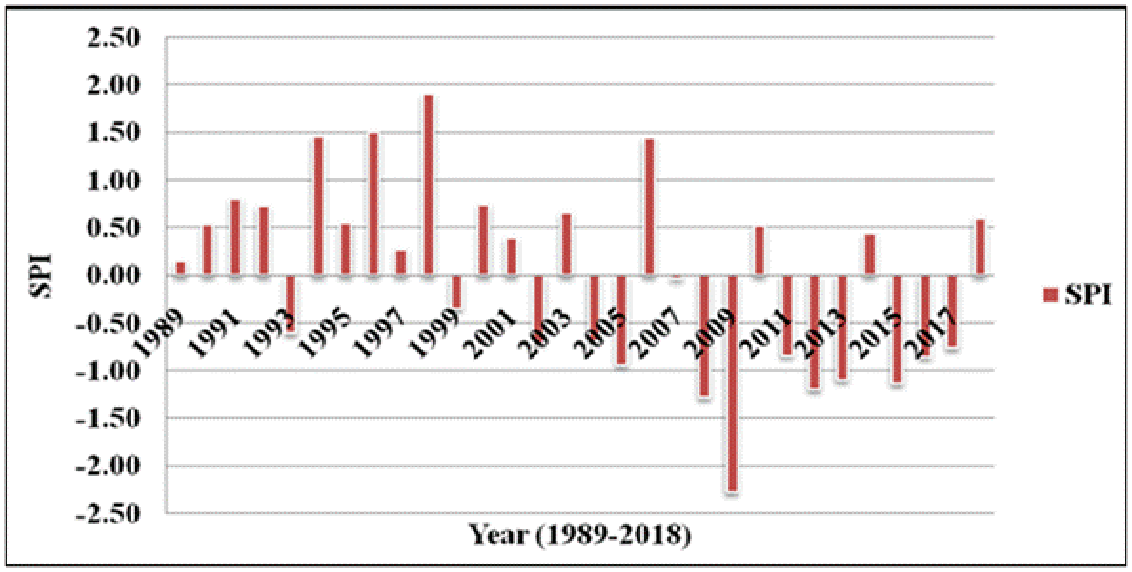

Figure 5: Standardized Precipitation Index (SPI) for Emba Alaje District

Source: NMA Maichew station, Tigray, Ethiopia

4.3.2 Temperature variability and trend

The mean monthly temperature was analyzed across the Southern Tigray zone using the data collected in Meteorological station recorded over the last thirty years. The slope of all months shows a positive value implying an increase in the mean monthly temperature. The mean minimum and maximum temperatures 10.0°C and 21.2°C were recorded in the months of December and June respectively in the study area (Table. 5). The maximum temperature at June months' implies late onset of the rainy season which affects the crop planting time.

Moreover, December (7.94%) and February (7.88%) were the months that showed significant variations in the mean monthly temperature. February (1.17 ^{0}C) was the month of high deviation of temperature, while the most stable month was March standard deviation of 0.67 ^{0}C (Table 5).

Table 5: Values of temperature trend analysis of the Emba Alaje district (1989-2018)

Months	Minimum	Maximum	Mean	Std. Deviation	CV (%)	R-value	Slope	R^2-Value
Jan	12.10	15.00	13.47	0.67	5.05	0.191	0.015	0.036
Feb	13.10	18.40	14.83	1.17	7.88	0.453^{*}	0.06	0.205
Mar	14.60	17.30	16.06	0.61	3.87	0.479^{**}	0.035	0.247
Apr	14.80	18.90	17.14	0.80	4.69	0.534^{**}	0.049	0.286
May	15.20	19.40	18.10	0.90	4.97	0.502^{**}	0.051	0.252
Jun	16.20	21.20	19.43	1.03	5.31	0.579^{**}	0.051	0.335
Jul	15.20	20.00	18.00	1.07	5.96	0.505^{**}	0.062	0.255
Aug	14.90	18.60	17.36	0.82	4.75	0.477^{**}	0.044	0.228
Sep	15.50	17.50	16.73	0.59	3.55	0.427^{*}	0.029	0.183
Oct	12.40	16.30	14.80	0.86	5.76	0.579^{**}	0.057	0.335
Nov	10.30	15.30	13.67	1.11	8.12	0.540^{**}	0.068	0.292
Dec	10.00	14.70	12.88	1.03	7.94	0.380^{*}	0.044	0.144

There was also a positive and increasing trend in the annually mean temperatures recorded over the past 30 years (1989-2018) in the area. In this regard the average minimum, maximum and mean temperatures have been rising by 0.044 ^{0}C, 0.053 ^{0}C and 0.048 ^{0}C per year respectively (Figure 6). Consequently, the present study implies that the continuous temperature rising in the area could be attributed to the climate change and resulting in negative impact on crop production in many ways.

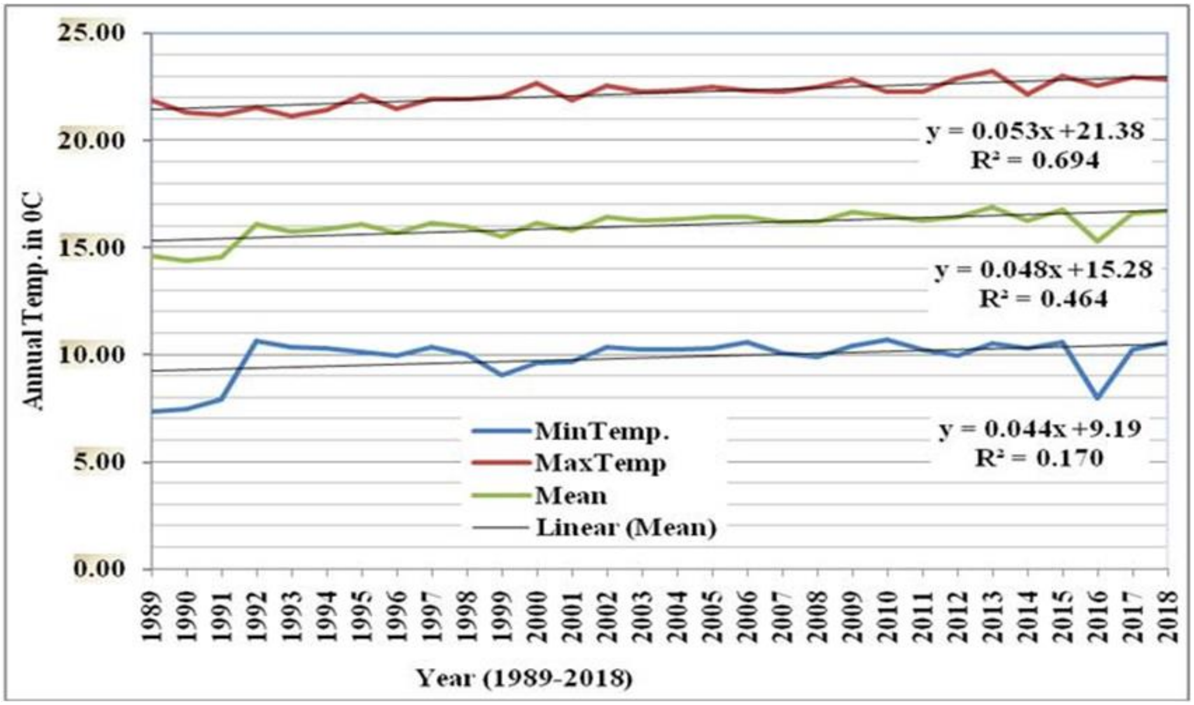

Figure 6: Trends of Annual maximum, minimum average and temperature (1989-2018)

Source: NMA, Maichew Station, southern Tigray, Ethiopia

As indicated in Figure 6 there was a general increasing annual maximum and minimum temperatures change from 1989 to 2018 years. Although the increasing rate of all minimum, maximum and the mean are all above the national (0.01°C) rate of annual increase, especially the increasing rate (0.053°C) of the annual maximum temperature in the area is quite alarming.

UNDP's (2008) report also revealed an increasing trend of mean annual temperature of Ethiopia. In addition, National Meteorology Agency of Ethiopia (NMA, 2001), disclosed that, the average annual maximum temperature in the country has increased by 0.1°C per decade, whereas, the average annual minimum increased by 0.37°C per decade (NMA, 2007).

It is evident that, increasing temperature leads to higher rate of evapotranspiration and moisture stress which increases duration of drought, thereby resulting in failure of crop productivity. This result is in line with Conway and Schipper (2011), who reported that an increase in minimum, maximum and average temperatures in Ethiopia in the coming decades will affect crop production.

4.4. Impacts of climate variability and change on crop production

The impacts of climate variability and change on crop production in the study area are negative, despite they substantially vary among crops types/or and varieties (IPCC, 2015). The results from experts' focus group discussions of this study emphasized that, climate change had caused; dry spell, late onset and early cessation of rainfall, high incidence of pests and diseases and seasonal flooding that negatively affected crop production. Especially cereal crops which are the main stable food have been significantly affected by climate variability and change in the study area (Table. 6).

In general, declining and variability of rainfall as well as increasing temperature are among the major factors affecting crop production and productivity in the area. The study of Anandh (2011) also revealed that, rising temperatures lead to crop failure through lowering crop water availability, causing heat stress and increasing pollen sterility of crop plants.

The perceptions of respondent farmers of the current study were asked about the adverse impacts of climate variability and change on crop production, 51.2% of them perceived that reduced crop yield, while 21.6% perceived fluctuated crop productivity, and 14.5% perceived increasing pest and diseases as a result of changes in temperature and rainfall over the past 12 years (Table. 6). Whereas, 3.3% of the respondents perceived that, climate variability and change caused loss of crop quality and 1.9% perceived total crop loss in the study area.

Table 6: Respondents observation on impact of climate variability and change on crop production in Emba Alaje district of Tigray region (n=365)

Impacts of climate events	Agro ecological zones						Total	
	Highland		Midland		Lowland			
	n	%	n	%	n	%	n	%
Total crop loss	3	2.4	3	2.1	1	1.0	7	1.9
Reduces crop yield	61	49.2	73	51.4	53	53.5	187	51.2
Reduce production land	26	21.0	38	26.8	15	15.2	79	21.6
Increases pest and disease	21	16.9	13	9.2	19	19.2	53	14.5
Delayed crop maturity	4	3.2	7	4.9	2	2.0	13	3.6
Loss of indigenous crop varieties	5	4.0	4	2.8	5	5.1	14	3.8
Loss of crop quality	4	3.2	4	2.8	4	4.0	12	3.3
Total	**124**	**100**	**142**	**100.0**	**99**	**100**	**365**	**100.0**

n = numbers of respondent, % = percentage of respondent

On the other hand, according the household survey of this study revealed that, 48.8% of the respondent farmers consider wheat as the most impacted crop while, 26% of them assumed sorghum as most affected (Table. 7). The study also showed that, barley was relatively better adapted crop to the negative impacts of late onset and early cessation of rainfall and high incidence of pests and diseases than long season crop types like sorghum in the area.

Table 7: Most impacted crop types by climate events in Emba Alaje District

Major crops	Frequency	Percentage (%)
Barley	8	2.20
Wheat	178	48.80
Tef	27	7.40
Beans	57	15.60
Sorghum	95	26.0
Total	365	100.0

4.5 Trend of crop production in Emba Alaje district

In this study the data used to estimate the impact of climate variability on crop production comes from secondary sources including CSA, BoARD. The sample size of the data ranges from 2007/08-2018/09. Cereal crops are the principal staple food, sources of income and animal forage for the majority of the smallholder farmers in the study area. Among the major crops, wheat is the predominant crop followed by beans and barely, although, sorghum and tef are also important according to the observed cultivated area in the production seasons. The production land of wheat, tef and sorghum in the area shows a decreasing trend and highly fluctuation time to time, while the cultivated area of faba bean and barely showed increment over past twelve years in the study area (Table. 8). Wheat and faba bean were the crop type of higher deviation in area of production land.

Table 8: Trends in cultivated area of major crops in Emba Alaje district during main season (2007/08-2018/09)

Crop type	Cultivated area (ha)			
	Std. Deviation	R-value	Slope	R^2-Value
Wheat	1.868	-0.251	-0.13	0.063
Barely	1.251	0.786**	0.273	0.61
Tef	0.539	-0.877**	-0.131	0.769
Sorghum	0.856	-0.166	-0.039	0.028
Faba bean	1.909	0.755**	0.40	0.57

The correlation coefficients computed for rainfall and major crop productivity showed positive relationships (Table 9). The correlation analysis for each crop yield indicated that, sorghum had strongly direct correlation with summer and annual rainfall; while wheat and faba bean had intermediate correlation. On the other hand, barley and tef showed weak correlation with summer and annual rainfall patterns. Therefore, enough amounts of summer and annual rainfall are important for proper production of major crops, especially for long season crops like sorghum. Whereas, the correlation of the mean annual temperature of the main season with the productivity of major crops showed positive relationships except for faba bean, implying the negative impacts of increasing temperature on its yields as a typical highland crop.

Table 9: Pearson correlation coefficient summer and annual rainfall, mean temperature and yields' of major crops in Emba Alaje district (2007/8-2018/19)

Variables		Productivity correlation coefficient of major crops				
		Wheat	Barely	Tef	Sorghum	Faba bean
Summer Rainfall	Pearson Correlation	0.405	0.238	0.230	0.943**	0.359
	Sig. (2-tailed)	0.191	0.456	0.472	0.000	0.251
Annual Rainfall	Pearson Correlation	0.386	0.177	0.087	0.762**	0.397
	Sig. (2-tailed)	0.215	0.581	0.787	0.004	0.201
Mean annual Temperature	Pearson Correlation	0.589*	0.648*	0.610*	0.044	-0.052
	Sig. (2-tailed)	0.044	0.023	0.035	0.892	0.873

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

In general, the crop production sector shows sluggish growth during the first two years (2007/08-2008/09), whereas there was remarkable change in terms of production and area coverage during the last one decade. However, population growth and increasing demand for food has surged, leading the sector to a steady growth in the last decade. On the other hand, crop production activities were affected by climate variability and change, and making difficult for farmers to maintain food security. The majority of the households were therefore forced to depend on food aid programs from the government, especially in the lowland and midland agro ecological zones, since highland areas of the district gate better rainfall amount and have favorable soil condition for crop production.

The findings of this study showed that climate change, especially rainfall variability has negatively impacted on crop production and productivity in the area. Therefore, climate adaptation and mitigation measures are required to reduce the long term vulnerability of crop production and food insecurity in the study area.

4.6 Climate change adaptation options on crop production

This study revealed that the communities have been implementing various adaptation measures to avert the negative impacts of climate variability and change on crop production (Figure. 7). Similarly, Boko *et al*., (2007) reported that for most of African poor countries including Ethiopia, practicing adaptation strategies is not an option; rather it is a necessity to survive in the changing climate. Accordingly, the rural communities who perceived the existence of climate variability and change are practicing intensification of agricultural crop inputs and technologies including change crop types or/and varieties, soil and water conservation practices, crop diversification, crop rotation, increasing irrigation farming and adjusting planting time as adaptation strategies.

According to household survey results 37.8% of the respondents use drought resistant or early maturing crop varieties, while 22.2% practice soil and water conservation as adaptation strategies to overcome impacts of climate variability and change on crop production (Figure 7). The remaining respondents implement crop diversification, crop rotation, supplemental irrigation and adjusting planting time to adapt the negative impacts of climate variability and change in the study area.

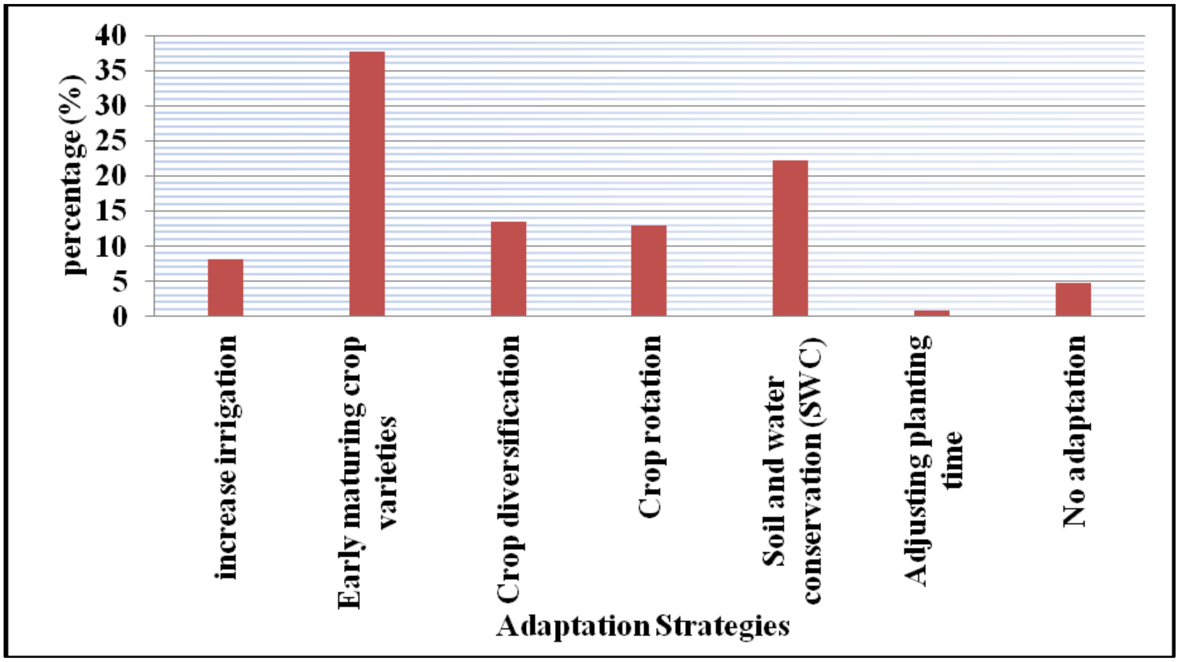

Figure 7: Primary adaptation strategies in response of climate change impacts

FGD participants and key informants also revealed that, smallholder farmers practice different adaptation strategies to reduce the impact of climate variability and change impacts on crop production in the study area. The results of focus group discussion and experts pointed out that, using of early maturing crop varieties and moisture conservation practices were the most effective adaptation options they use to reduce the effects of climate variability and change on crop production.

However, about 4.7% of the respondent smallholder farmers were not practicing any of the aforementioned adaptation options in the study area (Figure. 7). The major constraints hindering them to practice diverse climate change adaptation strategies existing in the area to their full potential and intensify their agricultural crop production include; high cost and shortage of farm inputs as reported by 28.23 and 13.42% of them respectively (Table. 10).

In addition, there are constraints limiting their ability to implement different adaptation strategies such as; shortage of farm land, poor potential for irrigation, non availability of credit facilities, and high cost of farm labor and farm lands. Especially lack of sufficient capital hindered the farmers from getting the necessary agricultural inputs and technologies to reduce the negative impacts of climate variability and change in the area. Poor access to information sources and inadequate knowledge of smallholder farmers are also considered as another constrains to adapt the climate change impacts. Farmers in the study area also did not have sufficient family labor and were not able to employ laborers.

Table 10: Major constraints of climate change adaptation at Emba Alaje district, Tigray region

Major constraints of adaptation CC	Total number of respondents	Respondents in %
Shortage of land	39	10.68
High cost of farm land	25	6.85
Poor access to information sources	19	5.20
Non-availability of credit facilities	27	7.40
Poor potential for irrigation	30	8.23
Non-availability of farm inputs	49	13.42
High cost of inputs	103	28.23
Inadequate knowledge	10	2.74
Non-availability of farm labor	12	3.28
High cost of farm labor	29	7.94
Lack of money	22	6.02
Total	365	100

4.6.1 Determinants of farmers' choices of adaptation strategies to climate change

The Multinomial *Logit* model was employed to estimate the determinants of farmers' choices of adaptation practices to reduce the negative impact of climate change. In this study, "no adaptation option" was used as base category and the estimated coefficients weighted against the base category. The model was tested for the validity of the independence of irrelevant alternatives using assumptions by Hausman specification test procedure. The difficulty of multicolinearity among the independent variables was tested via variance inflection factor and contingency coefficient for continuous and dummy descriptive variables, respectively. In both cases, no problem of multicolinearity was detected.

The MNL model results showed likelihood ratio statistics from the model indicated that Chi-square test (297.69) was highly significant ($P < 0.0001$), suggesting the model has a strong explanatory power (Table.11). Therefore, the marginal effects of the MNL result the expected change in odds of a particular choice being made with respect to a unit change in the explanatory variables (Table. 11). The result showed that the explanatory variables influenced in using one or a combination of climate change adaptation strategies identified by farmers.

Farmers living in different agro ecological zone use diverse climate change adaptation strategies. The MNL revealed farming in midland decreases significantly the probability of using irrigation and soil and water conservation by 23.34 and 53.7%, respectively as compare to farming in lowland ($p < 0.05$). On the other hand, farming in midland increases significantly the probability of changing crop types 37.16%, compared to the farmers living in lowland ($p < 0.01$). This difference might be happening due to difference soil fertility, climate and other related problems as well as experience to climate related stresses. In line with this, Tesso *et al*. (2015) and Legesse *et al*. (2013) also reported that farmers living in different choice of climate change impacts.

As gender of respondents' analysis showed male headed households increase the likelihood to increase change crop varieties, crop diversification, soil and water conservation and irrigation practices as climate change adaptation strategies (Table.11). However, being male headed household decreases significantly the probability of using adjusting planting time by 71.8% when compare to female household heads, holding other variables constant ($p<0.05$). In general, male headed households have greater preferences for these climate change adaptation strategies that require labor, finance and information than female headed households. This agrees with argument that male headed households are more likely to get information about new technologies than female headed households (Asfaw and Admassie, 2004).

Age of the household head, revealed that one year increases in the age of households head significantly increases the probability of adapting change in crop type/variety, crop diversification, soil and water conservation and irrigation practices by < 0.001, 1.1, 1.27 and 0.29% respectively. This might be related to the fact that older farmers are able to assess the available technologies, gained enough knowledge experience and technical expertise on the adaptation options; and also enable them to make adoption decision (Gbetibouo, 2009).

Education of the household head significantly increases the use of irrigation practices as climate change adaptation strategies. One year increase in the number of years of schooling was associated with a 1.41% increase in irrigation use. Farmers' with higher education are likely to have more information on climate change, which in turn might promote the probability of adopting climate change adaptation strategies. This result was similar to that of

Deressa *et al.* (2009) and Tesso *et al.* (2012). Beside, extension service expected to visit the households' positive influence on the probability of adopting the prevailing adaptation options. Result of MNL model showed that a unit increase in extension contact is expected to increase the probability of the farmer to adopt change in crop type and /or variety by 0.07%. Increase access to extension service has increase the probability of using climate change adaptation options in different parts of Ethiopia (Deressa *et al.*, 2009; and Tesso *et al.*, 2012).

The result revealed that increased access to credit is expected to increase the probability of the household head to practice irrigation as climate change adaptation strategy by 22.75%. Thus, irrigation is one of the most effective climate change adaptation strategies to avoids crop failure due to moisture stress and enable farmers to cultivated year round. Therefore, access to credit service also plays a positive role for farmers to adapt climate change adaptation options. However, leveraging the cash shortage of households through credit might encourage farmers' to engage in irrigation practices. Deressa *et al.* (2009) and Tesso *et al.* (2012) also observed that increase in credit access significantly enhance the farmers' choice of climate change adaptation strategies.

Access to meteorological advisory significantly increased the probability of using crop diversification, soil and water conservation and irrigation practices by 9.47, 14.73 and 10.85%, respectively (Table.11). This result implies the important role of increased institutional support in promoting the use of adaptation options to reduce the negative impact of climate change. This result confirm the finding of Mulat (2013) who showed that increase in access to climate information increases farmers' likelihood to prefer crop diversification and change in planting date as climate change adaptation options.

Table 11: Determinants of farmers' choices of adaptation strategies to climate change at Emba Alaje district, Tigray region

Explanatory variables	Change crop type/variety			Crop diversification			Soil and water conservation			increase irrigation			Adjusting planting time		
	Coef	P value	ME	Coef	Pvalue	ME	Coef	P value	ME	Coef	P value	ME	Coef	P value	ME
Sex of HH	1.028	0.500	0.0006	0.465	0.730	0.113	1.140	0.391	0.463	2.031	0.193	0.141	-2.77**	0.026	-0.72
Age of HH	0.2007**	0.010	9.7e6	0.198**	0.011	0.002	0.212***	0.007	0.013	0.213***	0.008	0.003	0.080	0.268	-0.017
Extension service	2.477*	0.081	0.0007	0.662	0.610	-0.073	1.323	0.299	0.151	0.937	0.498	-0.007	0.622	0.606	-0.070
Credit access	1.061	0.488	0.0005	0.388	0.787	0.061	0.164	0.907	0.077	3.500*	0.055	0.227	-1.550	0.249	-0.367
Agro-ecology	20.24***	0.000	0.371	-0.317	0.826	0.162	-3.83***	0.004	-0.537	-4.59***	0.001	-0.233	1.108	0.381	0.236
Wealth status	0.0008*	0.083	1.7e-7	0.0003	0.478	0.000	0.0006	0.170	0.000	0.0007	0.156	8.6e06	0.0007	0.133	0.000
Education level	0.5803	0.229	0.0000	0.782	0.104	0.017	0.654	0.174	-0.021	0.817*	0.090	0.014	0.637	0.178	-0.009
Farming size	0.978	0.812	0.0003	-0.448	0.913	-0.173	0.677	0.868	0.122	0.981	0.811	0.062	0.376	0.926	-0.011
Meteorological advisory	1.136	0.420	-0.001	2.978**	0.033	0.095	2.681**	0.043	0.147	3.916**	0.025	0.108	1.068	0.379	-0.347
Const	-38.8***	0.000		-16.8***	0.000		-15.6***	0.000		-21.2***	0.000		-7.30*	0.058	
Base category	No adaptation options														
Number of observations	365														
LR chi-square	297.69														
Log likelihood	-218.78														
Pseudo R^2	0.405														

***, **, * Significant at 1, 5, and 10% probability level, respectively; ME: marginal effect; Coef: regression coefficient;

5. SUMMARY AND CONCLUSION

5.1. Summary

This study was undertaken to; assess the relationship of climate variability and change impacts and crop production, predict the trend of rainfall and temperature using different statistical models; and identify perception and adaptation options used by smallholder farmers' in Emba Alaje district, Southern Tigray, Ethiopia. It employed stratified random sampling technique and multiple stage sampling procedure to collect quantitative and qualitative data for the study site. Both open ended and closed questionnaires were developed for interview with a semi-structured questionnaire. Primarily and secondary data were also used to gather the required information related to the impacts of climate variability and change on crop production. Analysis of rainfall and temperature characteristics (for Maichew meteorological station) was used for the period from 1989-2018 and the major crop production (wheat, barley, tef, sorghum and faba bean) was undertaken for the period 2007/8-2018/19. The obtained quantitative and qualitative data from survey were analyzed using descriptive statistical methods. Long term trends and relationship of climate mainly temperature and precipitation with crop production; as well as adaptation strategies were used to generate statistical indices.

Assessment of the profile of the respondent households in the study Kebeles revealed that their socioeconomic set up is weak and highly vulnerable to climate change, with substantial number of the respondents lacking adequate resources needed to adapt the negative impacts of climate change on crop production.

In this study, the analysis of major and minor rainfall seasons showed significant variability with decreasing trend, although it was relatively higher in the latter season. The high variability of rainfall in the both seasons inversely correlated along with the increasing in time series, while the average minimum and maximum temperatures were with increasing trend and positively correlated. Accordingly, the impacts of climate change and variability on crop production showed reduction in crop yield and fluctuated crop land coverage. However, the negative impacts of climate change varies among crop types or/and varieties depending on drought and pest resistance and growing agro ecology as well as fertility and water holding capacity of the soil. The slope of crop production land in the area therefore shows a negative value implying a decreasing and highly fluctuation time to time. The correlation coefficients computed for summer rainfall and major crop productivity showed positive relation, which implies that, the yield of major crops is declining due to climate change especially rainfall variability and decline. Moreover, the results showed that, the most of the farmers have perceived changes in climate and experienced the effects of a changing climate on crop production in the district. However, some respondents were not practicing any of the aforementioned adaptation strategies mostly due to limited financial capacity to practice diverse climate change adaptation strategies in the study area.

The findings also revealed that changes in crop type or/and variety along with proper soil and water conservation are the most important climate change adaptation options practiced in the area. The level of education and age of household heads, wealth status, extension service and meteorological information positively influenced the use of one or combination of climate change adaptation strategies identified by farmers. Gender of household head was also found to influence the choice of adaptation strategies by the farmers. Moreover, the agro ecological settings where the farmers are living significantly affect the farmers' choice of climate change adapting strategies.

5.2 Conclusion

According to the results of the current study, awareness creation and knowledge generation among the farming community as well as proper financial support to implement suitable adaptation options are vital and timely requirements so as to reduce the negative impacts of climate change and variability and improve crop productivity. Therefore, it is important and timely to establish meteorological stations and generate meteorological advisory services along with availing credit facilities in order to enhance crop production in the study area.

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APPENDIX

Anex1. Quantitative household survey questionnaires

This research's aim is to assess the impacts of climate change and variability on crop production; and identify adaptation options used by small holder farmers' in Emba Alaje district, Southern Tigray, Ethiopia.

I. General information's

District……………………….. Kebele………………….. Village………………………..

Household code…………………..

Name of house hold head………………………… Age of HH head (years)………….

1. Sex of household head ………………………….. 1. Male 2. Female

2. Marital status: 1. Married …….; 2. Single ……; 3. Divorced......; 4. Widow …….

3. Religion: 1. Muslim……… 2. Orthodox.....; 3.Catholic…..; 4. Protestant ………

4. Family size: How many people live in your house including the household head?

Male ......….; Female ……….; Total ………; of the household members, how many of them are dependents (have very little labor to production activity/ income generation activities of the household)? Male ………Female ………Total ……………

5. Wealth status of HH head: 1. Poor ….; 2. Medium ……; 3.Rich …… (Use secondary data).

6. What is the formal educational status of HH head?

   1. None (Illiterate)…….. 2. Primary………… 3. Junior……….. 4. Secondary……

7. What is the informal educational status of HH head? 1. None (Illiterate)…. 2. Educated….

8. How do you rate health situation in your family?

   1. Very poor …………; 2. Poor…………; 3. Good………; 4. Very good ………..

9. What is total land holding size of your household? ....

1. < 0.25 ha 2. 0.25-0.50 ha 3. 0.51- 0.75 ha 4. 0.76-1.0 ha 5. > 1.0 ha

10. How well-off is your household today compared with the situation 5 year ago?

1. Less well-off......; 2. about the same ……; 3. Better off now ……

If less worse or better off: can you rank the main reason for the change? Please rank the most important response, maximum 3.

1. Off farm employment ….; 2. Land holding (e.g.; bought /sold land)…..;

3. Forest resources….; 4. Output price (forest, agriculture)…….

5. Outside support (government, NGOs)…………..;

11. How do you rate your general health wellbeing? 1. Very good 2. Good 3. Medium 4. Low

12. For how long do you live in the village? ....

13. What is the farming system of the household head?

1. Rain fed farming 2. Irrigated farming 3. Other (specify)

14. What is the farming experiences of HH head (years)?

1. < 5 ….. 2. 5-10 ……. 3. 11-15 ….. 4. 16-20 …… 5. >20 …….

15. Source of income of the household other than agriculture /off farm activity/

1. Livestock farming… 2. Dairy production…. 3. Petty trade….

4. Selling of fuel wood and timber for construction….. 5. Handcraft…

16. Could your production enough to feed the family for a year and above?

1. Yes……… 2. No…….

17. If 'No' for how many months is it sufficient?

1. 1-3………… 2. 4-6……….. 3. 7-9………….. 4. Others, 5. Specify…………

II. Institutions and information service

1. Are you a member of any farmers' group or cooperative? 1. Yes 2. No

2. Do you have access to early warning /meteorology information on Climate variability?

    1. Yes 2. No

3. Sources of climate related information and its' impacts? 1. Govt. focal agents 2. Local elders 3. Radio/TV 4. NGO 5. Own understanding 6. from other farmers

4. How do you rate weather related information timely, adequately, frequent and regular?
    1. Poor …; 2. Average …. 3. Good …;

4.1. Is information useful? 1. Yes ……….; 2. No ………….;

5. Do you have access extension services in the last 5 year? 1. Yes 2. No

6. How many times per season do you receive extension services? ....

7. Did you have access to agricultural credit in the last 5 years? 1. Yes 2. No

8. If 'yes' for what purpose did you spend? 1. Farm input… 2. Non-farm businesses………… 3. Education ……….. 4. Buy cattle…….. 6. Others (Specify)…

9. What is the source of the credit services? 1. Bank loan… 2. NGO…... 3. Co-operative……. 4. Community loan…… 5. Agriculture loan… 6. Micro credit loan……

10. Did you use market information services in the last 5 year? 1. Yes ….; 2. No ……..;

11. Did you use health insurance in the last 5 year? 1. Yes ……; 2. No …….

III. LAND CHARACTERISTICS AND CROP PRODUCTION

1. What is the total land owned/ used by your household? Before 10 yrs ago……. ha, B/r 5 yrs ago……..ha, B/r 1 yrs ago……..ha,
2. What is the total land owned by your household currently? Owned/ used by your HH….. Ha, leased/purchased……. ha, Total………. Ha
3. What types of crops are the most common/ major in the area?

1. Barely…. 2. Wheat… 3. Tef… 4. Beans…… 5. Sorghum…… 6. Other (specify)…

4. Which crop did you grow last season (2018)?

   1. Barely…. 2. Wheat… 3. Tef… 4. Beans…… 5. Sorghum…… 6. Other (specify)……

5. What is the soil type of your HH farm land?

   1. Sand, 2. Clay, 3. Sandy loam 4. Clay loam 5. Loam

6. Did your HH use irrigate or moisture harvest during 2018 growing season? 1. Yes 2. No

7. What is the method of irrigation used?

   1. Watering can 2. Sprinkler 3. Drip 4. Surface 5. Other (specify)……

8. Did your HH terrace during 2018 growing Season in their farm land area? 1. Yes 2. No

9. What was the proportion of the total terraced area?

   1. 25% or less 2. About 50 % 3. About 75% 4. 100%

10. Tillage methods: 1. Manual with hoe …; 2. Animal traction….; 3. Tractor……..;

11. What is the predominant environmental conservation practiced on your parcel of land?

    1. None…. 2. Agro forestry… 3. Terracing… 4. Fallowing… 5. Intercropping… 6. Others,

12. What types of water harvesting structure /technologies do you apply in crop farming?

    1. In situ …….2. Ex situ…….. 3. Pond construction……4. Others (Specify)…………

13. Status of your cultivated land fertility; 1. High fertile ….; 2. Fertile …; 3. Not fertile…..

14. Did you use input supply services in the last 5year? 1. Yes ……; 2. No ……….;

15. Which types and average amount per ha of agricultural input use in the last year?

    1. Organic fertilizers 3. Inorganic fertilizers 5. Bio fertilizer 6. Improved seed 6. Pesticides

16. What was the source of input used? 1. Local government 2. NGO 3. Agro-dealer 4. Cooperative 5. Ordinary market 6. Other (specify)……

17. How did the HH pay for [INPUT]? 1. Savings 2. Loans 3. Harvest sales 4. Other…

18. What was the main location of market for sale agricultural crop products? 1. Village market 2. District market 3. Farm gate 4. Wholesale market 5. Cooperative 6. Other (specify)…

IV. Impacts and adaptation strategies climate variability and change

1. What things observed in your live system in the last 10 year? (Answer should be **increase, decrease or same**) 1. Crop yield …; 2. Livestock disease …; 3. Soil erosion ….; 4. Crop type and varieties .; 5. Livestock product …; 6. Crop pest and diseases ….; 7. Human health ….; 8. Income from agriculture…; 9. Food availability ….;

2. How do you describe the type of change for each climate change related events in recent times (past ten years)? Answer should be 1. Increase, 2. Decrease 3. The same or 4. Do not know) 1. Level of temperature …….; 2. Amount of rainfall …; 4. The time for onset and end of wet season …

3. What are the potential impacts of climate variability and change (rainfall and temperature) on crop production in your district? 1. Total crop loss……. 2. Reduces crop yield……. 3. Reduce production land……… 4. Increases pest and disease….. 5. Delayed crop maturity…. 6. Loss of indigenous crop varieties……… 7. Loss of crop quality…….

4. Which crop type of crops is most affected with climate change and variability? 1. Barely 2.Wheat 3.Tef 4.Faba bean 5. Sorghum

5. How do you evaluate the impact of climate change related event in terms of crop production activities? (Answer should be 1. High negative, 2. Moderate negative, 3. Non, 4. Moderate positive, 5. High positive) 1. Moisture stress …; 2. Incidence of crop weeds/ pests ...; 3. Extraction of forest based product … 4. Incidence of animal diseases…; 5. Human disease ….; 6. Other specify …..;

6. How much crop yield did you lose due to climate variability extreme events? (Percent)

7. What are the adaptation measures have you perceived to cope with the effects of climate variability? 1. Increase irrigation … 2. Drought resistant and early maturing crop varieties… 3 . Crop diversification … 4. Crop rotation … 5. Soil and water conservation (SWC)… 6. Adjusting planting time… 7. No adaptation…

8. To what extent the community adaptation options are effective?

5. Very high ……. 4. High …… 3. Moderate …… 2. Low …… 1. Very low ……

9. Major constraints for implementation of agricultural adaptations to climate change. 1. Shortage of land… 2. High cost of farm land... 3. Poor access to information sources… 4. Non-availability of credit facilities… 5. Poor potential for irrigation… 6. Non-availability of farm inputs (improved seeds, fertilizers, pesticides)…. 7. High cost of inputs… 8. Inadequate knowledge… 9. Non-availability of farm labor… 10. High cost of farm labor….. 11. Lack of money….. 12. Other (specify)….

10. To what extent the government committed to address the root causes of climate change and variability?

	Before 5 years ago	now
5. Very high	……………………	………………………
4. High	……………………	………………………
3. Moderate	……………………	………………………
2. Low	……………………	………………………
1. Very low	……………………	………………………

Anex2. Qualitative questions for key informants interviewing in kebele level (climate change, crop production and adaptation option questions)

Name ………………………………….Position ………………………….

1. Do you believe there is climate change in your kebele?

2. If yes, what is the manifestations climate change in your kebele?

3. What are the solutions to climate change in relation to crop cultivation?

4. Which groups of people are more affected to climate change? Why?

5. What are subsistence farmers doing to adapt climate change on crop production?

6. What are the challenges and constraints to adapt to climate change on crop production?

7. How do the government /NGOs support subsistence farmers in relation to climate change?

8. Is there anything you want to add about climate change?

Anex3. Open end questions interview for key informants at woreda level (climate change, crop production and adaptation option questions?

Name ………………………………………Position …………………………………

1. Do you think there is climate change in the district?

2. If yes, how do you describe the problem climate change in the district?

3. Which kebelle / district are more affected to the effects of climate change? Why?

3. Which kebelle / district are more vulnerable to the effects of climate change? Why?

4. Do you asses' vulnerability to climate change? If so, how do you determine impacts climate change of locations and peoples?

5. What is the role of your organization in relation to climate change to improve crop production?

6. Does the government have plan to agricultural crop adaptation to climate change? If yes, can you explain?

7. What are the challenges and constraints to adapt to climate changes on crop production?

8. Is there anything you want to add about climate change?

Anex4. Open end questions interviews for the regional bureaus (climate change, crop production and adaptation option questions)

Name ……………………………………Position ……………………………

1. Do you think there is climate change in your zone?

2. If you yes, how do you describe the problem?

3. Do you asses' impacts of climate change on crop production? If so, how do you determine adaptation choose of locations and peoples?

4. What is the role of your organization in relation to climate change?

5. Does your organization have plans to agricultural crop adaptation to climate change? If yes, can you explain?

6. What are the challenges and constraint to adapt to climate change on crop production?

7. Have you perceived any changes in climate change in your area in the past 10 years?

8. If yes, to the above, what are those changes? And which of these changes are more important in terms of their impact on your crop production?

9. What aspects of the livelihood (This may refer to livelihood activities (e.g. agriculture, assets, such as livestock, human capital e.g. health, social capital e.g. capacity to work together among the community, livelihood out comes e.g. income from different sources, etc) of the local community are more affected by those climate change?

10. Compared to other community around your areas (This may refer to adjacent district /kebeles in the same or different agro ecology etc), do you think your community is more or less vulnerable to climate change?

11. When you concede different groups in or community, do you there are same groups who are more vulnerable to climate change? If yes, who are those groups? And why those groups more vulnerable? What the reasons for this difference in vulnerability?

12. Referring to each of the crop production activities that were significantly affected by climate change (question 3 above), how do you tried to adapt to these climate changes? What do you do to agricultural adaptation to climate change? And what constraints faced to adapt to climate change?

13. Is there a change in incidence of crop diseases in your area as a result of climate change? If yes, what are those diseases (you can also ask the same about livestock and plant disease or pests?)

14. How do you get modern (scientific information about climate change? (For example, do you listen radio about weather?)

15. Can you explain about support by government agencies or NGOs regarding problem caused by climate change?

16. Is there anything you want to add about climate change?

Those are the questions I have. Thank you for participating in this survey.