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Agricultural Susceptibility to Climate Change in Varied Ecological areas of Northwest Ethiopia

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ABSTRACT

Agriculture is the most susceptible sector to climate change-induced hazards due to the fact that it affects the two most important direct agricultural production inputs, such as precipitation and temperature. Therefore, this study analyzed the susceptibility of agriculture to climate change in three purposively selected agro-ecological area of Northwest Ethiopia. The quantitative climate data were obtained from Global Weather Data for Soil and Water Assessment Tool (SWAT) from 1979 to 2010 while data on crop production and perception of households towards crop yield trend were collected using structured questionnaire complemented with informants' interview and field observation. Analytical techniques such as simple regressions (SR), standardized precipitation index (SPI), one-way-analysis of variance (ANOVA), crop diversification index (CDI) and index of trend of yield (ITY) supported with descriptive statistics were used to analyze the data. The meteorology data reveal that climate is characterized by increasing annual temperature trend, greater inter-seasonal variation of rainfall, and alteration of wet and dry years in a periodic pattern over the past 32 years (1979 – 2010). Rainfall also showed decreasing tendency at a statistically non-significant trend. Huge unproductive land was reported in the fragile lowland (41 %) distantly followed by Dabat (21.32 %). These ecological contexts have worsened the susceptibility of agriculture to climate change-induced risks. The trend of crop yield stability index was found to be high in the fragile lowland against the official statistics. In fact, places located nearer to the sources of

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climatic risks continue to suffer from pervasive poverty. In conclusion, ecologically designed agricultural systems that can provide a buffer against extreme events need to be the primary concerns of the regional government to minimize climate change-induced risks thereby increasing resiliency of rural households. Local leaders should enforce green laws through integrated land management practices that enable to regulate the local climate; sequestrating carbon dioxide and reducing climatic risks (drought and flood). In this regard, research should be done to find heat-tolerant seeds and to resolve the contradictory reports of official yield statistics and rural households' observations on crop yield trend.

Key words: Agriculture, ecology, climate change, crop diversification, Northwest Ethiopia, susceptibility, trend of yield

1. Introduction

Agriculture is the main source of livelihood, employment, and foreign exchange earnings in Ethiopia. It supports the livelihood of about 90% of the poor and generates 90% of the national export-trade and greater than 40% of the Gross Domestic Product (Slingo et al., 2005; Temesgen, 2010). However, the agricultural sector in Ethiopia is confronted with diverse environmental problems. Change and variability in rainfall patterns are supremely important determinant contexts of livelihoods construction in northern Ethiopia. They determine primary production from year to year, both in enhancing agricultural productivity and in conserving natural resources. This is very important to keep on sustainable agricultural production trend which is an important measure of overall contexts in maintaining the livelihood systems of the rural communities reside in different agro-ecological areas. The concept of agricultural susceptibility has emerged in response to concerns about the adverse environmental and economic impacts of traditional agricultural systems in the face of climate variability and change (Rasul & Thapa, 2003).

Ethiopian agriculture is mainly rain-fed in nature and exposed to uncontrollable natural hazards. Therefore, product (crop) diversification is an important method to reduce both natural and economic uncertainties. The concept of crop diversification (CD) is a scientific devise to study the existing spatial relationship of crops in association with other geographical contexts and land use dynamics (Vaidyanathan, 1992). Crop diversification is an important strategy to capitalize on the use of land, water and other resources for the overall advancement of agriculture in the country through providing the farmers viable options to grow various crops on their farmlands (Rasul & Thapa, 2003; Meena and O'Keef, 2007). A change in cropping pattern indicates a change in the proportion of farmland areas under different crops. However, the cropping pattern depends mostly up on agro-climatic, technical and institutional factors (Vaidyanathan, 1992).

Farmers practiced agricultural diversification with a view to avoid risks and uncertainties of climatic and biological vagaries. Moreover, it reduces the dreadful outcomes of the current crop specialization and monoculture by enhancing better resource use, nutrient recycling, reduction of risks and restock of soil fertility conditions. In fact, CD is very important to boost nitrogen in the soil, and to offer a reasonable quantity of the costly inputs like fertilizers, insecticides, pesticides and irrigation to the crops (Hussain, 2009). The over result of CD is to endow with better economic viability with a shift from low-value to high-value agricultural products and value-added manufactured goods suited to ecological sustainability.

The northern Ethiopia is located in the fragile landscape where rain-fed agriculture is the main source of livelihood for almost all the rural population and hence raising a serious concern about the susceptibility of agriculture in the face of deterioration of land quality, declining yield, and increasing population. Devoid of vegetation cover and the resultant severe soil erosion in the hilly areas and huge depositions in the low-lying areas are causes for agricultural productivity to go down from time to time. The recent climate change-induced weather risks add a new impact on smallholder agriculture via accelerated removal of topsoil and moisture from the farmlands. Certainly, the accelerated ecological degradation and climate change-induced floods, erratic rainfall, snowfalls, crop pests and disease, livestock disease, malaria and other human diseases, and small farmlands among other factors have direct effects on poor peoples' crop yield and food security in the northern Ethiopia (World Vision Ethiopia, 2007; Menberu, 2015, 2016).

Traditional mixed cropping, crop rotation, and intercropping also gradually disappear. This has led to mono-cropping and dependency on external inputs such as inorganic fertilizers, herbicides and pesticides. The increased uses of these inorganic inputs have led to contamination of soils, water bodies and the spread of diseases, which have adversely affected aquatic life, livestock and people (Rasul and Thapa, 2003).

Small-scale subsistence farmers are the most vulnerable social groups to climate change related hazards like droughts and floods. In spatial terms, dry sub-humid, semi-arid and arid areas are also susceptible to desertification and drought events (Temesgen, 2006; Ministry of Finance and Economic Development/MoFED, 2007). A recent vulnerability mapping in Africa grouped Ethiopia in the most sensitive countries to ecological change as it is heavily dependence upon rain-fed agriculture (Girma and Fekadu, 2010). The long-term change in precipitation and temperature patterns is most likely to increase the frequency of droughts and floods (World Bank, 2010). Hence, climate change will highly upset the productivity of rural households' farmlands located in the fragile environments and will continue to suffer more in the future (World Bank, 2010).

The magnitude of climate change is increasing from time to time and worsening farmland degradations in different agro-ecological areas of northwest Ethiopia. Both increasing temperature and deficit in precipitation are currently observed in there. Droughts, flood and other extreme events are frequently occurring having severe effects on farmlands, soil fertility and overall crop yield.

Scholars have done research to measure the impacts of climate change on agriculture in developing nations, including Africa and Ethiopia (Temesgen 2006, 2010; Madison, 2006; Molla, 2008). For example, the study in pastoralist area conducted by Prolinnova and Pastoralist Forum Ethiopia (PFE) found out several adaptation options to reduce farmers vulnerability to climate change, regarding crop production; a research conducted in the Blue Nile Basin (Ethiopia) by Temesgen et al. (2008); analysis of rainfall variability and crop production in Amhara Region by Woldeamlak (2009), to mention a few. However, most of these studies are aggregated at national or State levels. So, all may not reflect local contexts of different agro-ecological area because site-specific issues require site-specific experience and knowledge (IPCC, 2007). Moreover, none of these studies analyzed rural households' agricultural susceptibility to climate change using crop diversification index (CDI) and trend of crop yield stability index approaches. This study, attempted to investigate agricultural susceptibility to climate change in different agro-ecological areas of northwest Ethiopia.

2. Materials and Methods

2.1. Site selection and description

The purpose of this study was to examine and compare agricultural susceptibility conditions to therefore,

climate change in different agro-ecological areas of Northwest Ethiopia. Therefore, in order to accomplish the proposed research with respect to the nature of the research objectives, three woredas (districts), namely Simada to represent the lowland-valley, Denbia to stand for the midland and Dabat to the northern (Semien) highlands were purposely selected (refer Figure 1).

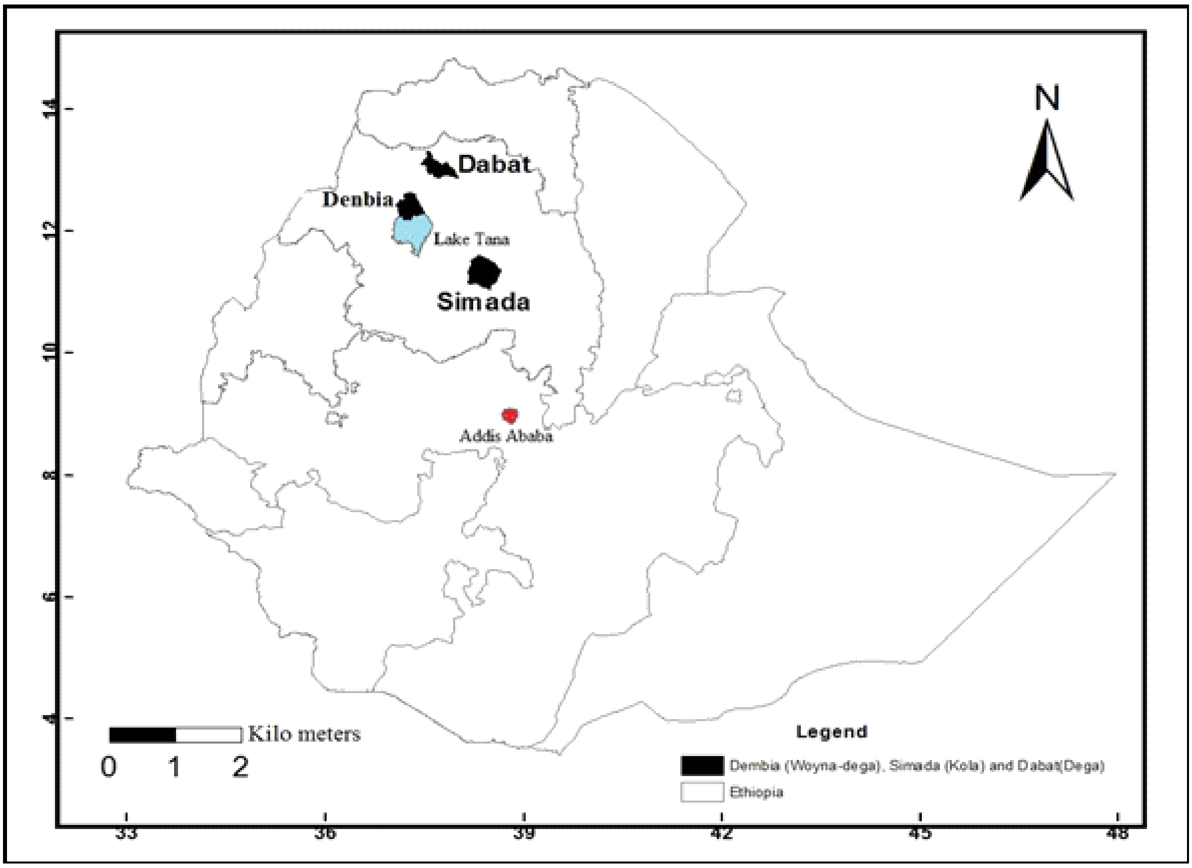

Figure 1: Location of study woredas in the national and regional setting

The motivation was to examine the differences in the variables of interest as these woredas which represent different ecological setting, climate conditions, population pressure, land degradation, access to various infrastructures and many other related factors. The purpose was to examine whether or not there is significant variation in agricultural susceptibility to climate change across the three agro-ecological areas.

Both Dabat and Denbia woredas are located in the North Gondar Zone of the Amhara Region. Dabat is bounded by Debark woreda in the north, Wogera in the south, Tsegede and Tach Armachiho in the west, and Debark and Wogera woredas together in the east (see fig.1). It is situated in the flat topography of the Semien highlands following the Gondar – Debark highway. The woreda capital, Dabat, is located 255 km North of Bahir Dar city and

983km from Addis Ababa (Dabat Woreda Communication Office, 2011).

Midland (*dega*) kebeles of Dabat are located in the north highland wheat-barley-sheep livelihood zone of the flat highland topography following the Gondar-Debark highway near to the highest peak of Ethiopia. The altitude of the study sites ranges from 2500 to 4517m above sea-level. Although this area is located in the northern highlands of Ethiopia, fortunately it is relatively flat highland with less soil erosion as compared with the lowland (valley) area. The selected areas of the highland and the midlands also have relatively abundant water resources for agricultural and domestic purposes (ACCRA, 2011) as compared to the lowland site.

Denbia woreda is bounded with Gondar city and Lay Armachiho in the north, Gondar Zuria woreda in the east, Chilga and Alefa weredas in the west and part of Lake Tana in the south. The woreda capital, Koladiba, is located 750 Km North of Addis Ababa which is branched to west from Addis-Gondar highway at Azezo. It is 35km away from Gondar city.

The midland *(woyna dega)* areas are situated in Denbia woreda with an elevation ranging from 1500 to 2500m above sea-level characterized by flat terrain, flood-plain, and wetlands. The woreda is entirely located in the Tana zuria growth corridor livelihood zone, which is considered to have relatively good potential for agricultural production (Denbia Woreda Office of Agriculture, 2011), but found to become vulnerable to climate change-induced extreme events. As such, the site is heavily affected by flooding, malaria and other water-borne diseases, crop pests and disease as well as livestock diseases.

Simada woreda is located in South Gondar Zone of Amhara Region about 774 km north of Addis Ababa and 209 km southeast of Bahir Dar city (Simada Woreda Office of Agriculture, 2011). The woreda is bordered on the southeast by the Beshilo River, which bounds it with South Wollo Administrative Zone, on the southwest by the Abay River, which separates it from East Gojam Zone, on the northwest by Wanka River, a tributary of Abay, with Estie woreda, and on the north and northeast by Lay Gaynt and Tach Gaynt woredas respectively. This indicates that the woreda is totally inclusive in the Abay River basin (Tibebe. 2008).

The lowland (*kola)* sites are located in dissected landscapes of Abay-Beshilo Basin of Simada woreda where land degradations, drought, food insecurity and famine are serious problems mainly since 1980s. It is totally included in the Abay River Basin. The elevations of the chosen study sites range from 854m to 1500m above sea-level though the elevation of Simada woreda ranges from 854 to 3000 m above sea level (extracted from Digital Elevation Model/DEM).

The three selected woredas are situated in northwest Ethiopia stretching from the Abay-Beshilo Basin to the northern (Semien) highlands, bearing similarities in some socio-economic aspects, but highly different in agro-ecological setting. For further understanding the sampling area is presented by elevation, temperature and rainfall limits in Table 1 below.

Table **1**: Sampling frame by elevation, temperature and rainfall limits

Agro-ecology	Elevation limit	Range of temperature (^{0}C)	Range of rainfall (mm)
Highland (Dabat)	2500 − 4517m	10−18	1200 – 2200
Midland (Denbia)	1500 − 2500m	18−24	900 – 1200
Lowland (Simada)	854 −1500m	24−28	200 – 900

Source: Based on FAO, 2003

FAO (2003) recognized that elevation with different terrain characteristics is a factor that determines the distribution of climatic factors and land suitability, which, in turn influence the crops to be grown, the rate of crop growth, natural vegetation types and their species diversity. In addition, the distribution of soil, land surface and climatic hazard frequency and severity, and production potential vary by terrain characteristics. In line with this, human sensitivity to climate change is strongly influenced by terrain characteristics settled by human population and pursuing their livelihood activities.

2.2. Sample size determination

Once the selection of the woredas was done, kebele administrations/KAs/ (the lowest administrative unit in Ethiopia) in the three woredas were grouped into three as highland, midland and lowland. Then, a total of eleven (11) KAs were randomly selected from all the woredas (3 from highland, 4 from midland and 4 from lowland). Further stratification of households in terms of annual income, household size, gender, etc was not done as the comparative nature of the study further complicates the application. Most importantly, it was assumed that systematic random sampling can accommodate households having these different criteria so as to obtain representative sample population. In the third sampling stage, sample size determination was carried out to obtain reliable data for the thesis. The Israel (1992) statistical formula was checked within the determination of the sample household size for a better representation of the study population. Accordingly, 576 households were randomly (simple) selected from the chosen KAs.

The formula provided 387 sample populations which represent 3.29% of 11,732 households of the eleven chosen KAs. This calculated sample size was considered as the minimum requirement based on Feige & Marr (2012). They contend that assuming the calculated sample size as sufficient to comply with the requirements is a typical mistake. The non-response and incomplete responses are mentioned as some of the reasons so that they suggest a compensation for such effects by increasing the calculated sample size by some proportion. Accordingly, the sample size for this study was increased to 576 (5%). Then, the 576 households were distributed to each KA using probability proportional to size (PPS) method to ensure equal representation of households as there are different household sizes in each agro-ecological zone and respective KAs.

The sample size determination formula provided larger number of household heads for lowland (363) distantly followed by the midland (181) and then the highland (132). The reasons are: 1) the lowland KAs in Simada cover larger area consisting of 4 to 6 church administrations while one KA considered from one to two church administrations in other study sites. 2) The lowland site is located around the upper Blue Nile Basin which was once very fertile though now the area is being highly degraded and still densely populated. In line with this, the CSA (2007) population and Housing Census of Ethiopia and other office documents indicate that most of the lowland KAs hosted high population while the highland KAs hosted low population number. From this, we can understand that global, continental and national generalizations are inconclusive in the dissected landscapes of northwest Ethiopia.

Systematic random sampling technique was used to select sample rural households. In the process, sampling frames (the list of all household heads), were taken from each KA offices. The sample households were drawn for each KA from the list of names after a certain sampling interval (K) that was determined by dividing the total number of households by the predetermined sample size of each kebele. Next, a number was selected between one and the sampling interval (K) which is called the random start using lottery method and was used as the first number included in the sample. Then, every K^{th} household head after that first random start was taken until reaching the desired sample size for each KA (Feige and Marr, 2012). Systematic sampling is to be applied only if the given population is logically homogeneous within the respective strata (agro-ecologies in this case), because systematic sample units are uniformly distributed over the population (Feige & Marr, 2012). In the case of this study, the sampling units are rural farmers who are uniformly distributed in the respective agro-ecology-based study sites.

2.3. Data collection methods

Data were collected from both secondary and primary sources. Secondary data include land-used for different crops, and crop production/productivity, and KA population data. The primary data were collected using household survey, focus group discussion, field observation, and in-depth interview which have brought the study to fruition.

Household survey was employed to collect quantitative data on crop yield and trends over the past 20 years or so from 525 randomly selected household heads. The actual household surveys were administered by data collectors with close supervision of me and assistants. The author's former university students had played paramount role in the process of data collection. They also played an important role in choosing the data collectors who have been working in the community in the areas of agriculture, healthy and teaching, with the academic status of diploma and bachelor degree. As a matter of fact they are living in the community for many years with the objective that they better know the area and easily approach and handle respondents.

In order to maintain the validity and reliability of the data, the questions were extensively reviewed by experts from different disciplines, working in the Offices of Agriculture, Health, and Food Security and Disaster Prevention. Additional pre-tests of questions were made by distributing questionnaires to 10 farmers in each site who were not involved in the actual survey to assess whether the instruments were appropriate and suited to the study at hand, and to delete or modify confusing and sensitive question and ideas. Necessary amendments were made based on the comments obtained from experts and responses from farmers to ensure reliability and validity; whether the questions made respondents feel uncomfortable and ensure the clarity of the questions as to whether they could be easily understood. Pre-testing of the questions was also used to determine the mean interview length and mean time required for covering the samples in order to plan the time and days required for the field survey and the number of data collectors. Data collectors were also trained with respect to the survey techniques and confidentiality protocol. Internal quality control procedures were established during the training. For example, in case survey questions contained ambiguous language that might lead to different answers depending on respondent's interpretation, data collectors were told to have common understanding. After the training, the data collectors acquired practical experience while I was making face-to-face interview in the actual data collection in the field.

The household survey was conducted in the period between March and September 2012. Household heads were approached, but if he/she were not available, the spouses were contacted. When difficulties were faced to meet the selected households due to absenteeism (after repeated visits) or when they became involuntary to take part, he/she was replaced by the household listed next to him/her. Most of the farmers were contacted on the homesteads and a few of them were consulted on Saturdays, Sundays, and other holidays around churches and community gathering places.

The qualitative primary data was collected using focus group discussions (FGDs), in-depth interviews, and field observation particularly for the purpose of checking the quantitative data (both primary and secondary). The 'why' and ‘what’ kinds of probing questions were also raised by the household survey questionnaire based on the households’ responses. In addition, the quantitative results which needed further reasoning from officials of both governmental and non-governmental agencies and farming households were also treated through these qualitative data collection methods.

In-depth Interviews: In-depth interviews were conducted with farmers progressively, before and after the questionnaire survey period. Attempts were made to develop a rapport with the community through short informal interviews. These discussions took place in the public meeting places, villages, and church compounds. Discussions with woreda and KA office heads, KA leaders, project managers, experts, and extension agents at various levels were held using guiding questions in the topic areas in their offices. A total of 15 officials and 6 Office heads from woreda Administration, Office of Agriculture, Disaster Prevention and Food Security and Organization for Rehabilitation of Amhara (ORDA) were approached for in-depth interviews. People who were assumed to have rich information were chosen. Creswell (2012) confirmed the importance of contacting these people by expressing his stand as “The standard for choosing the participants is whether they are information rich”. Similar to FGDs participant selection process, key informants such as research assistants, extension agents, KA managers, and respected figures of each kebele played important roles for identifying participants in in-depth interviews.

Field observation: Field observations were conducted in all the study areas in order to gain better insights into the selected study sites. The first contact was made with the heads and experts of the Departments of Agriculture at Zone Administrations to acquire basic information about the woredas, followed by visits to woredas and then KA offices. During these visits, discussions were held with office heads and experts to learn more about the agrarian systems, climatic hazards and types of interventions, which provided the general picture of the biophysical, economic, social and institutional features of the woredas. By doing so, I was acquainted with the specific agro-ecological zones included in the study.

Although visits were undertaken before, during and after the household survey, the actual field observation was conducted after the survey data collection was completed. Visits at an early stage of the fieldwork to different villages were found to be a good opportunity to meet the community members. In the process, I introduced myself to the community and the grassroots workers. The observation focused on physical features, flood and erosion-prone areas, crop patterns, and land management structures. Moreover, pictures were taken in the field to portray more vivid features of the study sites and to support the quantitative and qualitative works of the study.

The uses of these qualitative data gathering methods are recognized by Creswell (2012) by stating that qualitative inquirers triangulate among different data sources to enhance the accuracy of a study. Triangulation is the process of corroborating evidence from different individuals (e.g., a principal and a student), types of data (e.g., observational field notes and interviews), or methods of data collection (e.g., documents and interviews) in descriptions and themes in qualitative research. The researcher examines each information source and finds evidence to support a theme. This ensures that the study will be accurate because the information draws on multiple sources of information, individuals, or processes. In this way, it encourages me to develop a report that is both accurate and credible.

3.4. Data Analysis

This study used both quantitative and qualitative data analytical techniques. The former include simple linear regression (SLR), standardized precipitation/temperature index

(SPI) and crop diversification index (CDI), trend of crop yield stability index, supported with descriptive statistics such as mean, frequency counts, percentage, maximum and minimum values of a distribution.

Simple Linear Regression (SLR): SLR was used for analyzing temperature and rainfall trends as it is the most commonly used method to detect and characterize the long-term trend and variability of temperature and rainfall values at annual time scale (Mongi et al. 2010). The parametric test considers the SLR of the random variable Y on time X. The regression coefficient is the interpolated regression line slope coefficient computed from the data as was used by (Mongi et al. 2010) is:

$$Y = \beta x + c \qquad [1]$$

where, Y = changes in rainfall and temperature during the period; β = slope of the regression equation; x = number of years from 1979 to 2010; c = regression constant.

Standardized Precipitation Index (SPI): the SPI was used to identify droughts during the period under consideration using annual rainfall data. The SPI is a statistical measure to detect unusual weather events making it possible to determine how often droughts of certain strength are likely to occur. The practical implication of SPI-defined drought, the deviation from the normal amount of precipitation, would vary from one year to another. It can be calculated as:

$$SPI = \frac{X - \vec{X}}{\sigma} \qquad [2]$$

SPI refers to rainfall anomaly (irregularity) on multiple time scales; X represents annual rainfall in the year t; $\vec{X}$ is the long-term mean rainfall; and σ represents the standard deviation over the period of observation (McKee et al. 1993; Woldeamlak 2009). Hence, the drought severity classes are: Extreme drought (SPI<-1.65); moderate drought (-0.84 > SPI > -1.28), severe drought (-1.28 > SPI > -1.65); and no drought (SPI > -0.84).

Drought duration, magnitude, and intensity were analyzed based on quantified SPI values. Drought duration is the period between drought starts and ends expressed in months or years. Drought magnitude (DM) is the sum of the negative SPI values for all the months or years within the period of drought (McKee et al. 1993). Mathematically it can be expressed as:

$$DM = \sum_{j=1}^{x} -(SPI\ ij) \qquad [3]$$

where, j starts with the first month/year of a drought and continues to increase until the end of the drought (x) for any of the i time scales (the i^{th} month or year from the observation period).

Drought intensity (DI) is the ratio of the drought magnitude to the duration event, which can be expressed as Mi/Li where Mi is drought magnitude and Li is the drought duration (McKee et al. 1993). Although drought analysis used both the monthly and yearly time scale, the yearly scale was selected for detecting the long-term temporal patterns of drought in the studied area.

Crop diversification index (CDI)

Agricultural susceptibility to climate change was measured based on three indicators: cropping pattern, land productivity, and yield trend stability to get insights about the overall trends of crop production and reflect the health of an agricultural system in the face of climate change in spatially different agro-ecologies. Rasul and Thapa (2003) argued that there is a higher chance of agricultural susceptibility with decreasing land productivity and cropping diversification. High degree of cropping diversification is conducive to making efficient use of different types of nutrients available in soil and to increasing biodiversity. In addition, crop diversification reduces the risk of crop failure; thereby making farmers less vulnerable to food shortage resulted from climate variability and change. The opposite is true in areas where crop diversification is limited. Thus, the cropping pattern was examined by gathering data on the proportion of land allocated for major crops (cereals, pulses and others) using crop diversification index formula as was used by Rasul and Thapa (2003) depicted below:

$$\mathrm{ICD} = 1/((\mathrm{P_a} + \mathrm{P_B} + \mathrm{P_C} \ldots + \mathrm{P_n})/\mathrm{N_c}). \quad (4)$$

where, ICD = index of crop diversification; Pa = proportion of sown area under crop a; Pb = proportion of sown area under crop b; Pc = proportion of sown area under crop c; Pn = proportion of sown area under crop n; Nc = number of crops.

Index of trend of yield

Land productivity was measured through physical yield of crops collected by the household survey. One way analysis of variance (ANOVA) was employed to test the mean differences in crop yields amongst the three agro-ecologies. The stability of crop yield was analyzed using the formula of Ahmad et al. (2003) and Rasul and Thapa (2003) by constructing indices of trend of yield (ITY) based on farmers' responses to a question related to yield trend since the past 20 or more years ago as:

$$\mathrm{ITY} = (\mathrm{fi} * 1 + \mathrm{fd} * -1 + \mathrm{fc} * 0/\mathrm{N}) \quad (5)$$

Where, ITY = index of trend of yield ; fi = frequency of responses indicating increasing yield; fd = frequency of responses indicating decreasing yield; fc = frequency of responses indicating constant; N = total number of responses.

The quantitative data analysis methods were supported by the qualitative data processing methods. Thus, the qualitative method was used to analyze the information obtained through in-depth interview and field notes written during observations. The collected information was converted into word processing documents in the process of analysis. The author had taken some interviews and observational notes transcribed. Transcription is the process of converting interview, discussion and field notes into text data and then translated from local language (Amharic) to English for narrating and interpreting the issues through answering the 'why' and 'how' questions.

3. Results and Discussion

3.1. Temperature trends and anomalies

Temperature is a very important climate variable in the study of susceptibility of agriculture to climate change impact. Evidences indicate that the mean temperatures have changed through time in Ethiopia (NMA, 2001, 2007). The same temperature trend was detected in Dabat highland, Denbia midland, and Simada lowland agro-ecological areas of northwest Ethiopia over the past 32 years (Refer to Figure 2).

Greater temporal variability was observed in the three agro-ecological areas over the same period (1979-2010). The deviation was calculated using the SPI formula based on Mongi et al. (2010) (refer fig. 2)

Figure 2A demonstrates the maximum and minimum temperature deviations from the long-term average temperature in the highland from the period 1979 to 2010 average temperature. It is clear from the figure that around 1981 there was no much deviation both in maximum and minimum temperatures from the long-term average temperature. Since then both maximum and with fluctuation. In 1981 and 1982, equal variations (from the long-term average maximum and minimum temperatures) were detected in maximum and minimum temperature with certain decline as compared with the previous years. Since 2000, both the maximum and the minimum temperatures increased with greater fluctuations over time. minimum temperature deviations went down until 1989 and continued until 1994

While the minimum temperature continued its increment, the maximum temperature decreased after 2003 though after 2001 both the maximum and minimum temperature deviations were above the long-term average temperature except certain decline in maximum temperature in 2010.

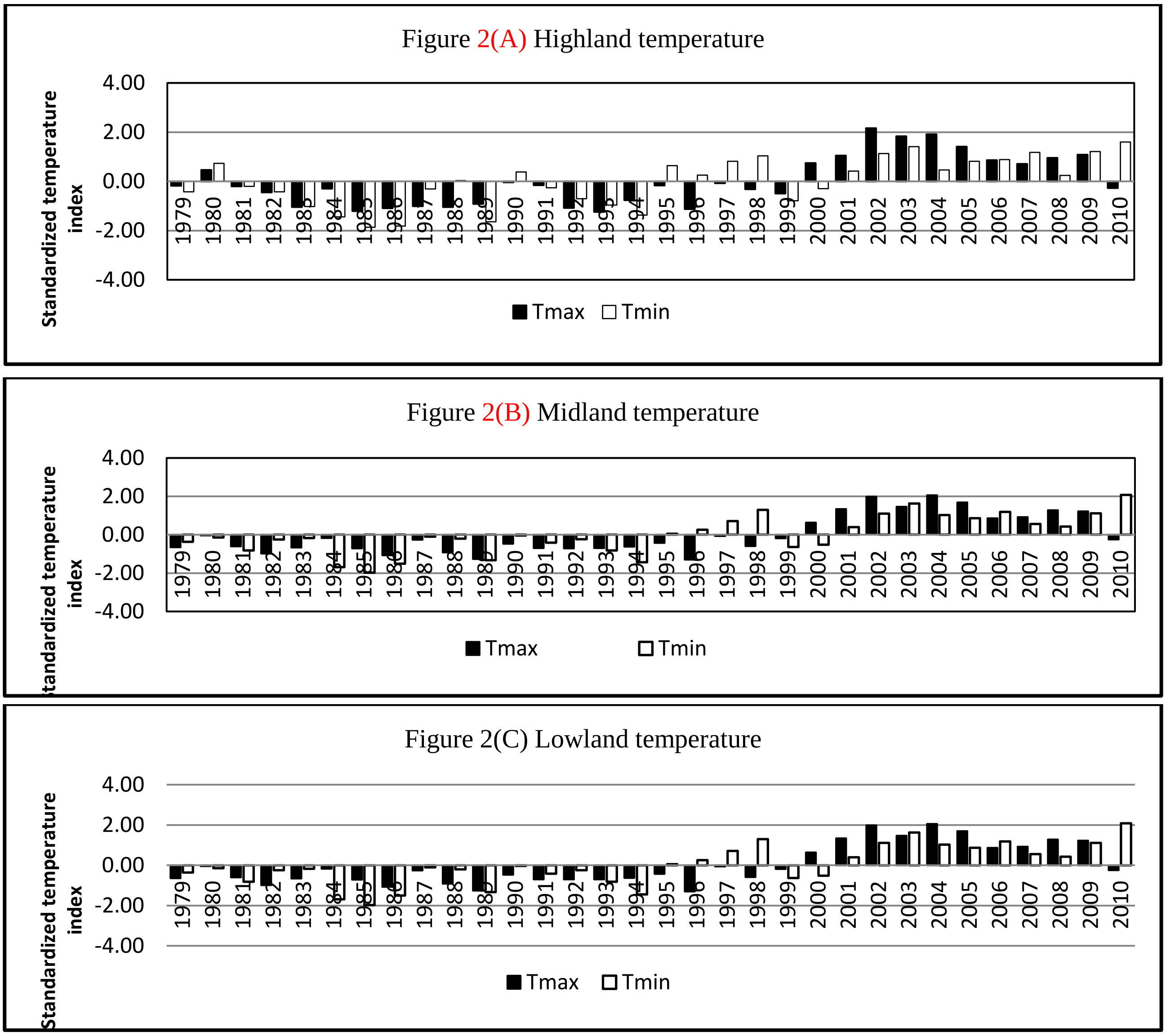

Figure 2(A) Highland temperature

Figure 2(B) Midland temperature

Figure 2(C) Lowland temperature

Figure 2 Highland (A), midland (B) and lowland (C) Maximum & minimum temperature in three agro-ecologies (2 years moving average)[**Source**: Computed from Global Weather Data [http://globalweather.tamu.edu/]**.**

Figure 2B presents the maximum and minimum temperature deviations from the long-term average temperatures for the highland site. It is clear from the figure that until 1984 the deviation between maximum and minimum temperatures was almost similar. After 1984, increasing trend of deviations were detected both in the minimum and maximum temperatures with greater fluctuations over time. Analysis of temperature trend showed similar trends as the one reported by IPCC (2007) and Mongi et al. (2010) both of which pointed out that increasing temperature trend in the tropical and sub-tropical regions of the world is very high (IPCC, 2007).

Figure 2C displays the maximum and minimum temperature variability (anomalies) in the lowland site. It is clear from the figure that, similar to the midland site, both maximum and minimum temperature anomalies have shown increasing trend as compared with the long-term average temperature. Although still there are fluctuations, the rate of increase in both maximum and minimum temperatures is much faster in the lowland than of the midland site. With regard to long-term temperature deviation/anomaly, the results in this study are in line with the findings of several other empirical works (Mongi et al., 2010; IPCC, 2013). The recent IPCC (2013) report confirms that in addition to multi-decadal warming, global mean surface temperature exhibits substantial decadal and inter-annual variability. Due to natural variability, trends based on short records are very sensitive to the beginning and end dates and do not in general reflect long-term climate trends.

3.2. SPI based drought analysis (1979- 2010)

Drought is a natural hazard, which can be marked, by precipitation deficiency that threats the livelihood resources and overall development efforts of nations or specific places through exacerbating water shortage for some activities. Therefore, analysis of drought frequency, duration, magnitude and severity is highly demanded for designing appropriate mitigation and adaptation actions. The standardized precipitation index (SPI) results presented in Figures 3A, 3B and 3C show the temporal drought patterns for the three agro-ecological areas.

Figure 3A shows the standardized precipitation index for the highland site. It is clear from the figure that the rainfall shows alternation of wet and dry years in a periodic pattern. From 32 years of observation, 18 years (56.25%) received below the long-term average rainfall whilst 12 years obtained above average. Consecutive negative SPI values were observed from 2002 – 2005 followed by a recovery in 2006 and 2007; again a fall in 2008 and 2009 and went up in 2010 was recorded. The 2002 rainfall amount emerged as the lowest record in the observation period, marking the extreme drought year in the study site. There were five moderate drought years from the 1980 to 2010 such as 1984, 1990, 1995, 2004, and 2009. The high SPI values indicate surplus rainfall and may be associated with flood years though there is no standard to classify the years in relation to flood occurrence. We can infer that the year 1979 stands first by the probability of flood occurrence with a positive SPI value of 2.69. The years 1998, 1997 and 1996 have positive values with SPI value of 1.56, 1.09 and 1.25 respectively.

The standardized precipitation index (rainfall anomaly – variability and irregularity) for the midland site is shown in figure 3B. Similar to the highland area, the rainfall is described by alteration of wet and dry years in a periodic pattern. Out of 32 years, 14 years (43.75%) recorded below the long-term average annual rainfall while 17 (53.13%) years recorded above-average. Only the year 1999 received equal rainfall amount with the long-term average. Most of the positive SPI values occurred before 1990 (9 out of 12 years). Consecutive negative SPI values occurred from 1990 to 1995 and 2002 to 2004. The 2002 rainfall amount was the lowest record in the observation period with SPI value 2.67. According to the drought assessment method by Agnew and Chappel (1999) referred by Woldeamlak (2009), there were seven drought years in the period spanning from 1979 to 2010 in the site, with varying severity. There were one extreme (2002), and four moderate (1990, 1991, 1992 and 2008) drought years, and one severe drought, which together account for 21.88% of the total number of observations. In contrast, 1998 was the wettest year in the period followed by the year 1996 (almost consistent with the anomalies of Amhara region by Woldeamlak (2009). This wettest year may be associated with the probability of flood incidences with SPI values of 1.87 and 1.45 in the years 1998 and 1996 respectively.

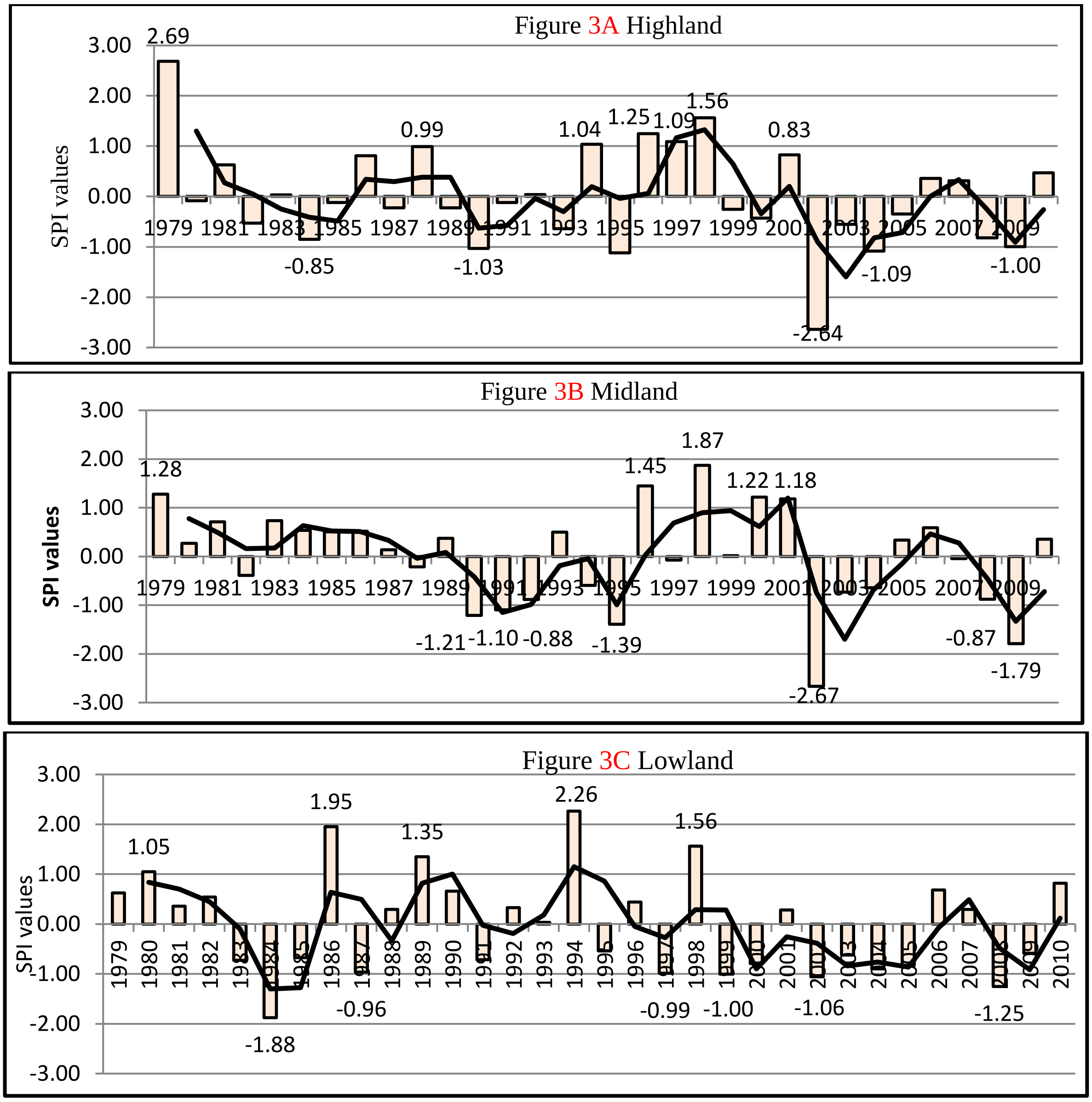

Figure 3 Highland (**A**), midland (B), lowlands (C): Standardized precipitation index with 2 years moving average

[Source: Computed from Global Weather Data [http://globalweather.tamu.edu/]]

Figure 3C demonstrates the standardized precipitation index for lowland study area (1979 – 2010). It is clear from the figure that rainfall is characterized by periodic fluctuation of wet and dry years. Out of 32 years of observation, 15 years (46.88%) recorded below the long-term average annual rainfall and the rest 15 years recorded above the long-term average. Only one year received nearly normal rainfall in the period (1983).

Before 1983, the rainfall was above the long-term average whilst from 1983 to 1995, it was below the long-term annual rainfall. Again, in 1986

positive SPI value was detected in spite of its failure in 1987. Likewise, a positive trend was identified from 1988 to 1990, but drier condition was experienced in 1991. Once more, slight recovery was observed from 1992 to 1993 with alternate rise and fall until 1998. Most of the negative anomalies occurred after 1998. The amount of rainfall in the years 1984, 1987, 1997, 1999, 2002, and 2008 were the lowest on record in the observation period, marking the worst drought years. Then, the rainfall indicated a recovery in 2006 from the low values of 1999 to 2005, but went down in the next three years (a large decline in 2008 and 2009), however. Again, the rainfall showed significant recovery in 2010. In the lowland site, five flood years were identified with high SPI values such as 1980, 1986, 1989, 1994 and 1998 with SPI vales of 1.5, 1.95, 1.35, 2.26 and 1.56 respectively.

Table 2: Summary of drought duration, magnitude and intensity by agro-ecology

Agro-ecology	Duration in year	Magnitude (−)	Intensity (−)	Span of time
Highland	18	12.16	0.68	1979−2010
Midland	12	12.54	1.05	1979−2010
Lowland	15	15.53	1.04	1979−2010

Source: Computed from Global Weather Data [http://globalweather.tamu.edu/]

Table 2 shows drought duration, magnitude, and intensity in the three study sites based on the calculated SPI values. It is apparent from the Table that long drought duration occurred in the highland site with 18 years, 12.16 magnitude, and 0.68 intensities. The drought characteristics in the midland site was found to be 12.54 magnitude and 1.05 intensity in the 12 years of duration whilst in the *kola* site, 13.53 magnitude and 1.04 intensity were computed in 15 years of duration. This result indicates higher drought intensity was detected for midland site, and hence it revealed that long drought duration is not necessarily the severe one. This finding is supported by Otgonjargal (2012) who underlined that drought year lasted for 17 months has higher magnitude (20.1) than the drought with a magnitude of 17.3 and 22 months duration indicating that longer drought durations are not necessarily the severe ones.

3.3. Land use patterns

Land resources can be used for different socio-economic purposes. As the data obtained from Offices of Agriculture and field observations indicate that the land use patterns of the study woredas is characterized by a mixture of categories: cultivated, unproductive, forests/bushes/shrubs, and grazing lands, water body, residential areas and others.

Table 3: Land use pattern for the three study woredas (Dabat, Denbia and Simada)

Indicator	Unit	Dabat		Denbia		Simada	
		Area	Percent	Area	percent	Area	Percent
Annual & perennial crops	Hectare	28307	22.96	50118	33.42	98989	43.30

Unproductive land	"	26305	21.34	23765	15.85	92813	40.67
Vegetation &bush land	"	13068	10.60	8416	5.61	554	0.24
Grazing land	"	15200	12.33	19004	12.67	21445	9.40
Water body	"	6505	5.28	13113	8.74	4806	2.11
Residential area	"	19243	15.61	6510	4.34	9765	4.03
Others	"	14657	11.89	30042	20.03	-	-
Total area	"	123285	100	149968	100	228172	100

Source: North Gondar Zone and Simada woreda Offices of Agriculture, 2011

Crop production is the dominant type of land-use and the main source of subsistence in all agro-ecological settings. It is clear from Table 3 that 43.3% of total land area of Simada, nearly 23% of Dabat, and 33.42% of Denbia are used for agricultural purposes. The second proportion of land cover is found to be degraded unproductive lands – nearly 41% of Simada, 21.32% of Dabat and 16% of Denbia − which is the worst context that can aggravate the vulnerability situation of the study areas to climate change-induced risks. Residential areas cover 15.61% of Dabat against 4.34% of Denbia and 4.03% of Simada. Grazing land constitutes almost equal proportion in Dabat and Denbia (over 12%), against 9.4% in Simada. Vegetation and bush lands coverage have been significantly declined from highland (10.6%), through midland (5.61%) to valley areas (0.24%). The remaining land area is utilized for other purposes without significant variation across agro-ecological zones. This finding is consistent with the household survey and interview data. In the highland relatively better prospect was observed in tree plantation, survival, and wood supply trend than the midland and valley areas, with the worst situation in the fragile valley areas.

3.4. Cropping patterns

As Table 3 above indicates, the dominant land area has been allocated for crop cultivation. Thus, cropping pattern was investigated through proportion of land under major crops (mainly cereals and pulses) by analyzing crop diversification index (ICD) as was used by Rasul and Thapa (2003) depicted in equation 4. Crops occupying less than 3% of cropped area were excluded from the analysis. The 9 major crops in the midland, 7 in the highland and 4 in the lowland were taken for analysis. Table 4 presents the major crops and the crop diversification index values.

Table 4 indicates the proportion of area coverage by different crops. There is considerable variation in cropping patterns in the three agro-ecologies. For example, the average land area used for the cultivation of three dominant crops namely, wheat (29.37%), barley (27.63%), and beans (25.7%) are found to be nearly 83 percent in the highland area. Cereal crops mainly wheat and barley occupy significantly more than half of the cropped area. Whereas, the dominant crops in the midland agro-ecology are *teff* (26.57%), fruits and spices (16.55%), maize (16.12%), barley (8.04%), chickpeas (7.9%), and sorghum (6.72%). Wheat, millet, and grass pea all together constitute only 14.28% of the cropland in the same agro-ecology. While the number of crops cultivated in the lowland (valley) areas are found to be very limited as compared to other agro-ecologies. The main crops which all together constitute over 92% of the cropped area are sorghum (29.01%), haricot bean (24.15%), *teff* (21.1%, and maize (18.05%). Pulses including peas, beans, lentils and chickpeas represented more than 32% of the highland and 20% in

Table 4: Crop diversification index by ecological setting

Crop Type	Highland (N = 7)	Midland (N = 9)	Kola (N = 4)
	Area in %	Area in %	Area in %
Teff	3.71	24.68	21.1
Barley	27.63	11.52	1.04*
Wheat	29.37	3.15	2.93*
Millet	-	3.03	-
Oats	-		-
Maize	-	16.12	18.05
Sorghum	-	3.36	29.01
Peas	3.07	7.65	2.19*
Beans	25.7	1.5*	1.46*
Chickpea	0.46*	6.95	0.47*
Grass pea	-	2.23*	0.21*
Lentil	3.28	1.3*	1.15*
Haricot bean	-	0.64*	24.15
Potato	5.99	4.4*	-
Fruits & Spices	0.77*	9.52	-
Total percent	98.76	90.39	92.32
ICD	0.071	0.12	0.043

ICD= Index of crop diversification. The higher the index values, the higher the crop diversity.
Source: Kebele Office of Agriculture 2012 * excluded from analysis

midland of the cropped area against 4% in the valley (lowland) area.

Based on this proportion of cropped area, crop diversification index was calculated. The result reveals that crop diversity is very low in all agro-ecologies, perhaps, much lower in the lowland (0.0433) followed by the highland (0.071) than of the midland (0.12). The dominant crops cultivated by farming households are found only 4 in the lowland, 7 in the highland, and 9 in the midland. This very low crop diversification index is a vital

indicator of the context making agriculture unsustainable and in turn increases vulnerability situations of households to climate change-induced risks.

3.5. Crop productivity and trend of yield stability

Crop productivity per hectare and trend of crop yield stability are the most important contexts for measuring land quality and agricultural susceptibility to climate change in the three agro-ecological areas. To measure the quality of land, crop yield was analyzed based on the data collected from a household survey. In the survey questionnaire the households were asked to give the amount of major crops produced in quintal in drought and non-drought conditions. For analyzing crop productivity, the average yields of the drought and non-drought years were calculated to obtain annual crop yield per hectare for different crops based on Ahmad et al.

(2003). Then the average of the major crops of the three study sites were taken for analysis using One-way analysis of variance (ANOVA). The mean yield of major crops for individual households was also presented in a scatter plot for making comparison across the three agro-ecologies. The households were also asked about the trends of their major crops' productivity per hectare (yield) over the last 20 years or so with the alternative responses of: 'increased', 'decreased' and 'constant'. The responses were analyzed using descriptive statistics and Equation 5. The results are demonstrated, interpreted and discussed in the sub-sections to come.

Crop productivity: The survey results indicated that crop production deviates over space and time due to variation in the quality of farmland and climatic conditions besides to other factors. There is considerable variation in the average productivity of cereals, pulses and other major crops by agro-ecology. Although it seems underestimated, average productivity was found to be five quintals per hectare in the highland (maximum = 19.3, minimum = 1.4, and standard deviation = 2.77), 4.32 in the midland (maximum = 13.6, minimum = 1, and standard deviation = 1.82), and 2.77 in *kola* (maximum = 10, minimum = 0.5, and standard deviation = 1.41) which is found to be much lower than the national average of one tone per hectare for cereals. This simply implies how agriculture in general and crop production in particular is performing differently in the three study sites against the national level average crop productivity/yield.

Table 5: Mean difference in crop productivity between agro-ecological areas

(I)Agro-ecology	(J) Agro-ecology	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
					Lower Bound	Upper Bound
Highland	Midland	0.68440*	.23848	.012	0.1239	1.2449
	Lowland	2.24136*	.20718	.000	1.7544	2.7283
Midland	Highland	-0.68440*	.23848	.012	-1.2449	-0.1239
	Lowland	1.55697*	.20560	.000	1.0737	2.0402
Lowland	Highland	-2.24136*	.20718	.000	-2.7283	-1.7544
	Midland	-1.55697*	.20560	.000	-2.0402	-1.0737

*The mean difference is significant at 0.05 [**Source**: Household survey, March – September 2012]

Table 5 shows the mean variation in crop yield between the three study sites. The Analysis of one-way Variance (ANOVA) significant at 0.05 level indicated that crop productivity in the highland area is found to be higher by 0.68 quintal than in midland and by 2.24 in the lowland site. In the midland, crop yield is higher by 1.56 quintals than in the lowland area. The degraded lowland places provided very low crop production consistent with the hazard of place model.

As the scatter illustration demonstrates (Figure 4), the majority of the households in the highland ecological area are concentrated above or around the mean yield of the three study sites. The great majority of the lowland and the midland households are concentrated under the mean yield. The reasons are attributed to poor rainfall timing coupled with high evapo-transpiration resulting from higher temperatures is expected to experience huge losses in production of major crops. The result is supported by the findings of the IPCC (2007) that crop production was projected to increase slightly in the cooler regions for local mean temperature which rose up to 1-3°C. This may be due to the beneficial opportunities that climate change has brought by increasing growing seasons for crops despite climate change aggravates land degradation. The IPCC's report also supported the lowest crop yield recorded in the lowland site which underlined that in the dryer and tropical regions crop yield is going down even with small local temperature increases (1-2°C) with further increasing risk of hunger.

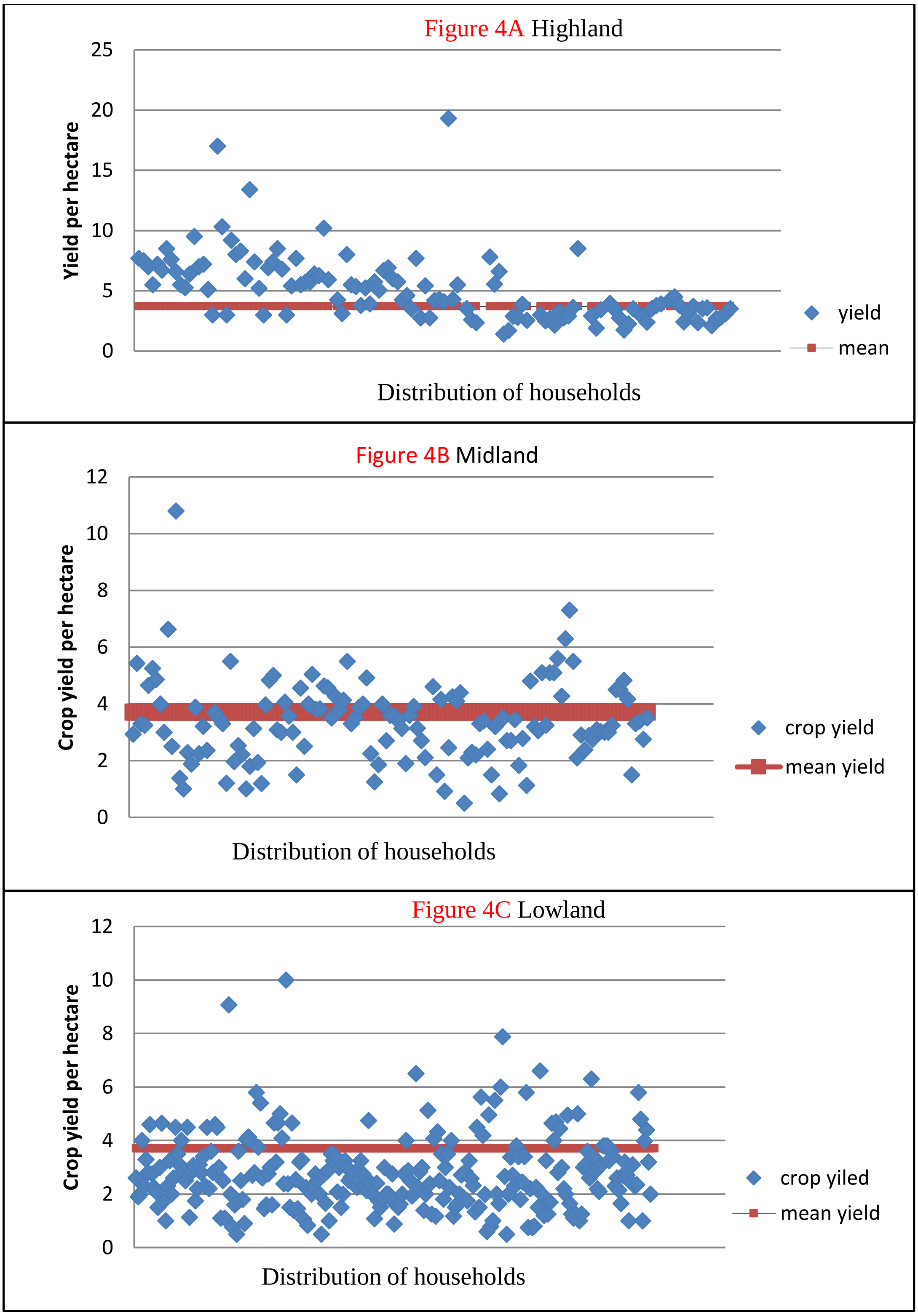

Figure 4: Yield of major crops against mean yield of the three agro-ecologies [Source: Household survey, March to September 2012]

Trends of crop yield stability: The trends of crop yield stability through time are also important contexts to measure land quality and agricultural sustainability/vulnerability of the rural households. In this regard, the rural households were asked whether crop yield has shown improvement for the past 20 years or so. Based on the households' responses, frequencies and percentages for the three responses of increased', 'decreased' and 'no change' were first computed and then a trend of crop yield stability indices were calculated using Equation 5 based on Rasul and Thapa (2003). See results presented in Table 6.

Table 6: Index of trend of yield stability by ecological areas

Ecology	Increased Constant		Decreased				Trend of crop yield index
	Frequency	% age	Frequency	%age	Frequency	% age	
Highland	20	15.5	103	79.84	6	4.7	- 0.64
Midland	17	12.8	106	79.7	9	6.8	- 0.67
Lowland	10	3.8	243	92.4	4	1.5	- 0.91
Total	47	8.95	452	86.1	19	4.33	- 0.78

Source: Household survey, March to September 2012

Table 6 presented the frequency of responses and trend of crop yield stability indices. It is very clear from the table that larger proportion of the lowland (92.4%) households than those in the highland (79.84%) and midland (79.7%) reported decreasing crop production pattern in the past 20 years or so. Only 15.5% of surveyed households in the highland, 12.8% in the midland and 3.8% in the lowland sites observed an increasing trend. The rest perceived no change.

The index results revealed the negative trend of crop yield in all the three study agro-ecological areas (−0.91) in the lowland (−0.67) in the midland and (−0.64) in the highland, particularly with higher rates of crop yield decline in the lowland. The overall index value for the three ecological areas was found (−0.78), indicating a higher rate of crop yield declining tendency since the past 20 years ago. However, contradictions between official agricultural statistics and households' responses regarding crop yield were identified. The kebele agricultural experts, reported 50 – 80 quintals of crop yield per hectare in the fragile land of Abay-Beshilo Basin (lowland valley) which is quite unbelievable and hence not useful to substantiate the findings on crop yield. Experts working in the field have a tendency to inflate production figures because their work performance is mostly evaluated based on the reported figures. The author triangulated this report taking it to older household heads. They absolutely rejected the experts' reports even before 40 and 50 years ago when there was surplus production, this very high crop productivity was not reported. Information provided by the households does justify that crop yields are gradually going down in their locality though it seems somewhat deflated for outside observers and general national observers. In addition, as the author was born, grew up, and worked in the farming households, crop yield is going down in the fragile landscape of northern Ethiopia. Triangulation was also done through visiting the households when they harvested and threshed their crops in the field which further justified the households' responses.

The above results does not mean that there is no growth in total production of the country as this is observed in its total agricultural production and in some households living in modest environmental conditions for new technology packages, good land management practices and irrigation justified reported increasing crop productivity over time. However, some scholars also related the effectiveness of new technology packages (at least partially) in boosting crop production with good weather conditions (Taffesse et al., 2011). They also argued that rather than technology adoption, the major factor behind the growth of total production in Ethiopia has been expansion of cultivated land area. For example, grain production has registered a growth of 74%, with yield growing by only 18% and area cultivated by 51% between 1989/90 and 2003/04. From 1994 to 2002, 70% of cereal production increases resulted from expansion of cultivated land area (Taffesse et al., 2011) and it is in an increasing trend in recent years. However, cultivable lands are already exhausted in the study sites so that there is no possibility of expanding agricultural land by households. Hence, the results seem logical for the fragile landscapes of northern Ethiopia where rain-fed crops are more sensitive to climatic anomalies. Rainfall variability is important determinant contexts of livelihoods of the community in Ethiopia. Good climate is needed to keep sustainable agricultural production for better livelihoods of households.

5. Conclusions

Agriculture is the most susceptible sector to climate change-induced hazards due to the fact that climate change affects the two most important direct agricultural production inputs and these are precipitation and temperature. Production changes of major food crops are the main drivers of well-being insecurity for the agrarian communities. This study examined agricultural susceptibility conditions under the impact of climate change in different agro-ecological areas of Northwest Ethiopia (Simada, Denbia, and Dabat woredas).

This study provides ample evidence about the issues considered. The context analysis found out that there are differential contexts, conditions, and trends across the three agro-ecological areas. More unfavorable biophysical and socio-economic contexts were identified in the lowland area having increasing exposure and sensitivity of the community to climate change and other stresses which have threatened the development efforts in the three areas. The changing patterns of rainfall, increasing temperatures, recurring droughts and massive land degradation have terrible effects for the poor people whose survival depends on rain-fed agriculture.

The meteorology data reveal that agriculture in the three study areas is found to be increasingly susceptible to climate change-induced risks. Annual temperatures in the study areas were in increasing trend for the last three decades (1979 – 2010). The most important feature of the rainfall data is the greater inter-seasonal variation. The total annual rainfall distribution is declining from time to time at a statistically non-significant rate in line with several empirical findings conducted in Ethiopia and other African countries. The rainfall is also described by alteration of wet and dry years in a periodic pattern over the past 32 years.

Crop cultivation is the dominant type of land-use in the three agro-ecological settings. Surprisingly, unproductive land was found to the second proportion of land cover in all the three areas though larger proportion was reported in Simada woreda (41 %) where there is environmental fragility distantly followed by Dabat (21.32 %) and 16% and Denbia (16 %). This worst environmental context has worsened the susceptibility of agriculture to climate change-induced risks in the study areas. The official crop yield data is against the data obtained from the household survey and key-informant interview.

The survey results indicated that crop production deviates over space and time due to variation in the quality of farmland and climatic conditions besides to other factors. There is considerable variation in the average productivity of cereals, pulses and other crops by agro-ecology. Productivity of crops were found to be much lower in the three agro-ecological areas than the national average of one tone per hectare for cereals though the degraded lowland areas provided very low crop production consistent with the hazard of place model. Similarly, trend of crop yields stability indices calculated based on the households' responses revealed the negative trend in the three agro-ecological areas with the overall index value of (−0.78), indicating very high crop yield decline from year-to-year.

This study also identified contradictory findings between official agricultural statistics and households' responses regarding crop yield trend. In the lowland/valley/ areas very low crop yield was reported consistent with the hazard-of-place model, which notes that geographic exposure to the sources of hazard influence the hazard potential. The parameter of sensitivity is strongly linked to location and is evaluated by the inherent characteristics of places, considering human-environmental relationship. Places located near the sources of climatic risks continue to suffer from low rates of economic growth and pervasive poverty.

In conclusion, context specific adaptation mechanisms are needed to minimize adverse effects of climate change-induced risks. This should be the fundamental concern to governmental and non-governmental
Competing interests: The author declares that there are no conflicting interests.

organizations through increasing resilience capacity of rural households. Local leaders should enforce green laws by encouraging peoples' integrated land management practices and tree plantation that enable to regulate the local climate by sequestrating carbon dioxide and reducing flood and drought risks. In this regard, research should be conducted on finding heat-tolerant improved seeds in the study area. Moreover, although official agricultural statistics heralded fast growth in yield and total agricultural production over the past years in the three agro-ecological areas, the surveyed households reported the contrary, decreasing crop production trend. Therefore, further research is needed in order to reconcile the contradictory reports of official yield statistics with rural households' reports on crop yield trend over the past years.

Authors' contributions

MT has made substantial contributions in designing the research, acquisition of the necessary data, processing the data, interpretation of results and leading the research activities. He has given also the final approval of the version to be published.

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