Impacts of Climate Change on Crop Production and Its Adaptation and Mitigation Strategies in Ethiopia

Abiyot Abeje[*1] and Melkamu Alemayehu[2]*

[1] Assosa University, College of Agriculture and Environmental Sciences, Assosa, Ethiopia

[2] Bahir Dar University, College of Agriculture and Environmental Sciences, Bahir Dar, Ethiopia

Corresponding author: abiyotabeje@gmail.com

Received: September 22, 2018 Accepted: May 12, 2019

Abstract: *Agriculture is the foundation of Ethiopia's economy where crop production contributes more than 65% of the agricultural GDP of the country. The impacts of climate change have been observed in Ethiopia over a long period of time which changes the environmental conditions that influence the livelihoods of the farmers and thus the national economy. Future climate projections showed continuing warming of the environment with varying rainfall patterns. The rain fed crop production, which is mostly practiced in the country, is highly vulnerable to climate change. The purpose of the present review is therefore, to review the impacts of climate change on crop production of Ethiopia and its adaptation and mitigation strategies. According to the results of the review, the main climate change hazards observed in Ethiopia are associated with rainfall variability including the amount, timing and intensity. Rainfall variability and recurrent drought lead to frequent yield losses and in sever conditions crop failures that result losses of property and even human life in the country. Smallholder farmers in the country are trying to use indigenous and improved crop production technologies as well as different management practices including selection of crops and or cultivars suitable to changing climate, adjustment of frequency and time of tillage, optimization of time of planting and its density, intercropping, traditional irrigation and water harvesting technologies. Rigorous natural resource management strategies including afforestation, promotion of agro-forestry, and use of renewable energy sources and development of land use plan were among others mitigation strategies of climate change implemented in the country. Capitalizing the existing development policies and programmers, development of research and extension services, improving the linkages between the respective stakeholders and awareness and understanding of local communities about the relationship between climate change and crop production are recommended to reduce the impacts of climate change on crop production of the country.*

Keywords: Crop failure, rainfall variability, recurrent drought, water harvesting, yield loss

1. Introduction

Agriculture contributes a remarkable proportion to the Ethiopian national economy, and the gross domestic product (GDP) is highly dependent on the performance of the agriculture sector. In recent years, a slight structural change from agriculture to the non-agriculture sector, specifically to the service sector, has been observed. The contribution of agriculture to GDP declined from 57% to 41% between 1996 and 2010 (Adefris *et al*., 2013). Though its contribution is decreasing, agriculture is still important as it contributes to economic growth of the country. It supplies raw materials to the industrial sector and 85% of the population is engaged in the sector. Moreover, agriculture contributes nearly 90% to Ethiopia's export earnings (FDRE, 2010).

Among the agriculture sector, crop production constitutes more than 65% of the agricultural GDP. However, climate change affects crop production of the country over a long period of time through changing rainfall distribution, increasing temperature and degradation of soil nutrients (reference). Climate projections show continued warming with very mixed patterns of rainfall change. Whenever the rainfall varies slightly, crop production and availability of food suffer considerably. Production and productivity of crops in Ethiopia is constrained mainly due to poor land use, overgrazing, poor marketing structure, inadequate transport network and low use of agricultural inputs (Adefris *et al*., 2013).

Ethiopia's history is associated often with major natural and man-made disasters that have been affecting the population from time to time. The country is therefore extremely vulnerable to drought and other natural disasters such as floods, heavy rains, frost and heat waves. Recurrent drought, famine and floods are the main problems that affect millions of people in the country. While the causes of most disasters are climate related, the deterioration of the natural system due to uncontrolled human activities and poverty has further exacerbated the situation (NMA, 2007).

As Ethiopian crop production is heavily dependent of natural rainfall, it is liable to the impacts of climate change. According to Nelson *et al*. (2009), the impacts of climate change on agriculture and human well-being can be expressed in various aspects. Among others, biological effects on crop yields, impacts on prices, production, and consumption as well as impacts on per capita calorie consumption and child malnutrition are the most important once. Therefore, climate change influences the efforts of the people to increase food production and thus reduces food security (IPCC, 2007). Therefore, the objective of this manuscript is to identify the impacts of climate change on Ethiopian crop production system so that to devise adaptation and mitigation strategies in order to combat food security problems in the country.

2. Climate Change in Ethiopia

According to National Metrological Agency [NMA] (2007), the environmental fluctuation has become a key issue in Ethiopia in the last few decades. The main climatic hazards in Ethiopia are expressed in terms of droughts and flooding. The most prominent trend in this regard is the tendency of lower rainfall during the main growing seasons in the country, which is occurring in the months of March to May and December to February. According to Adefris *et al*. (2013), rainfall declines by 15%, this is associated with anthropogenic warming of the Indian Ocean. Moreover, the onset of rainfall in the country is shifted (Adefris *et al*., 2013).

Historically, flood has never being taken as a major economic hazard in Ethiopia. However, flood occurred during the years of 1997 and 2006 were signs of climate change, which incurred significant socio-economic disruption in the country (NMA, 2007). According to NMA (2007), the country has experienced both warm and cool years over the last 55 years. In recent years, however, temperature showed an increasing trend as indicated in Figure 1. Over the last decades, the temperature in Ethiopia has increased by 0.2°C per decade. The increase in minimum temperature is pronounced with roughly 0.4°C per decade (Brohan *et al*., 2006).

On the other hand, precipitation remained fairly stable over the last 50 years when averaged over the country. The spatial and temporal variability of precipitation is relatively as indicated in Figure 3 (NMA, 2007), is high, thus large-scale trends do not necessarily reflect local conditions (Conway *et al*., 2009). According to NMA (2007), years like 1952, 1959, 1965, 1972, 1973, 1978,1984, 1991, 1994, 1999 and 2002 were dry while 1958, 1961, 1964, 1967, 1968, 1977, 1993, 1996, 1998 and 2006 were wet which were associated with El Niño and La Niña phenomena.

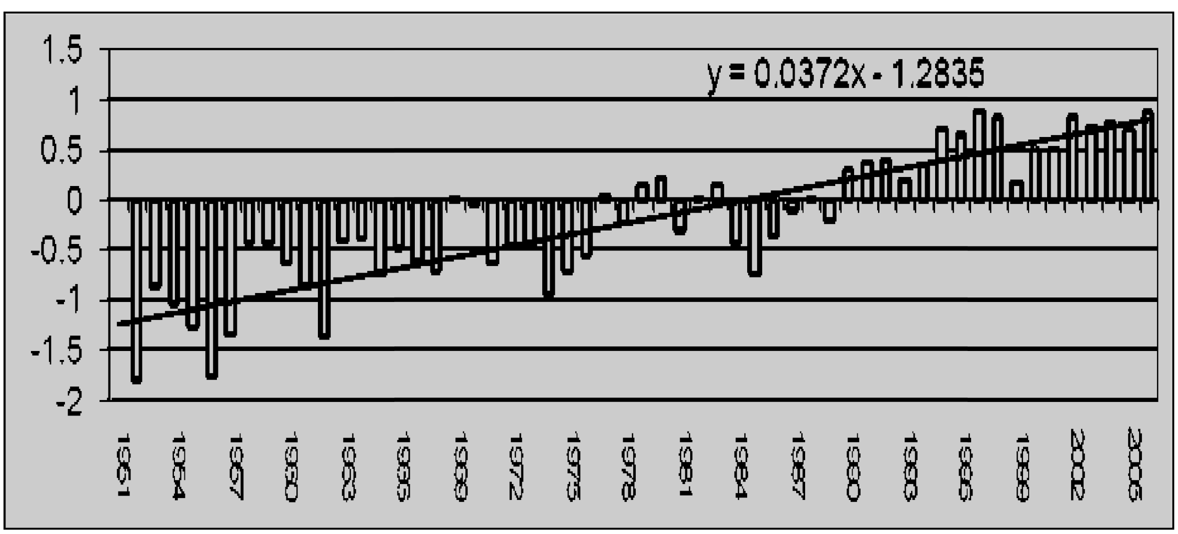

Figure 1. National average annual minimum temperature difference compared to 1971-2000 normal (NMA, 2007)

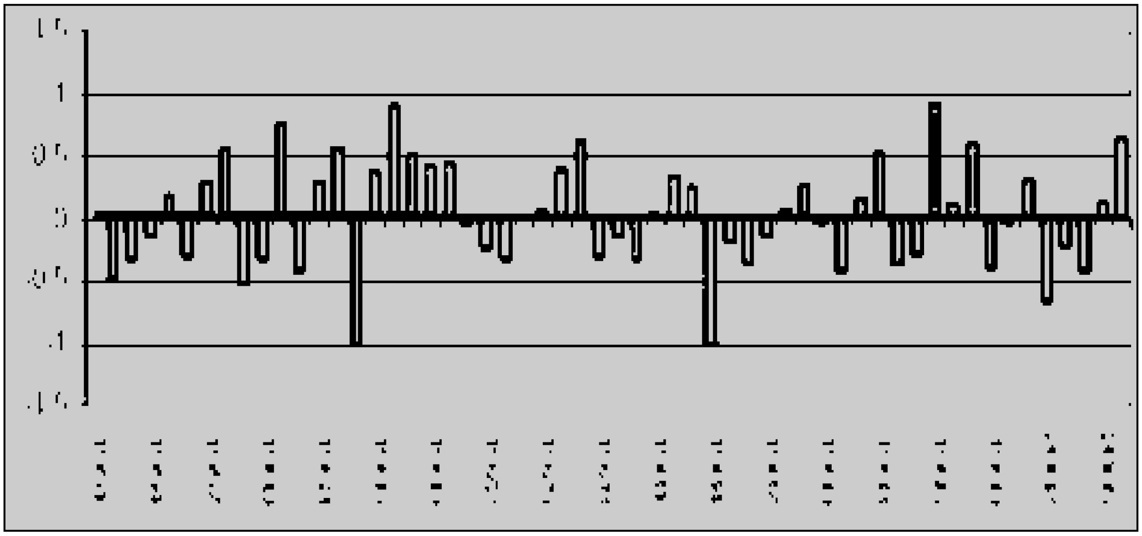

Figure 2. National average of standardized annual rainfall anomaly compared to 1971-2000 normal (NMA, 2007)

The future changes in precipitation and temperature in Ethiopia as projected by various global climate models are also shown in Figure 3 and 4. Most of the global climate models projected an increase in precipitation in both the dry and wet seasons of Ethiopia (Adefris *et al*., 2013). Other studies with more detailed regional climate models, however, indicated that the expected precipitation change is uncertain (Schneider *et al*., 2008). On the other hand, the temperature will very likely continue to increase for the next few decades with the rate of change as observed by Brohan *et al*. (2006).

The projected increases in the inter-annual variability of precipitation in combination with the increasing temperature will likely leads to increase the occurrence of drought. Moreover, heavy rain and flood are also projected to increase as well (Brohan *et al*., 2006). Decreases in rainfall amount will be exacerbated by higher evaporation rate, which is associated with increasing temperature. Projections of temperature are more certain to occur other than those of precipitations and considerable regional variations will exist (Brohan *et al*., 2006).

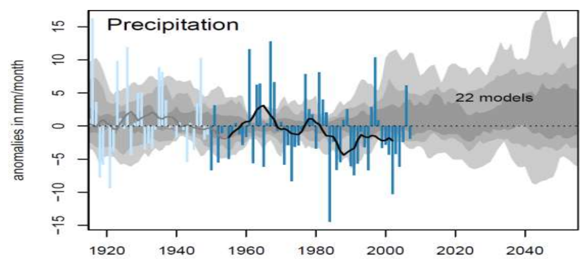

Figure 3. Observed and projected changes in precipitation in Ethiopia (Brohan et al., 2006)

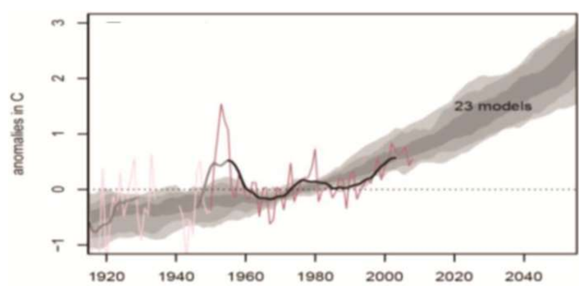

Figure 4. Observed and projected changes in temperature in Ethiopia (Schneider et al., 2018)

3. Causes of Climate Change and Ethiopia`s Contribution

The causes of climate change could be natural factors and/or human induced activities/anthropogenic factors. Human activities like burning of fossil fuels and agriculture together with widespread deforestation are emitting greenhouse gases including CO_2, nitrous oxide, chlorofluorocarbons (CFCs) and methane to the atmosphere, which absorb the thermal radiation emitted from the Earth's surface. The greenhouse gases are those gases in the atmosphere that absorb thermal radiation emitted by the Earth's surface, which have a blanketing effect upon it (Adefris *et al*., 2013).

The important greenhouse gases that are directly influenced by human activities are carbon dioxide, methane, nitrous oxide, the chlorofluorocarbons (CFCs) and ozone. Carbon dioxide is a good absorber of heat radiation coming from the Earth's surface, increased carbon dioxide acts like a blanket over the surface, keeping it warmer than it would otherwise be. The gas methane is also increasing because of different human activities, for instance mining and agriculture, are adding to the problem. Many scientists now believe that there is a direct link between this warming and emissions of greenhouse gases such as carbon dioxide (CO2), nitrogen oxides and methane. In addition to human factors, natural factors including volcanic eruptions affect global warming. Due to volcanic eruption, 25 million tons of carbon dioxide released to the atmosphere (IPCC, 2007).

The contribution of Ethiopia for global climate change is very low compared to other developed countries. According to Devereux (2006), the emission of greenhouse gases (GHG) in Ethiopia in 1994 was estimated to be 900 kg CO_2 equivalent per capita per year while USA emits about 23.7 tones CO_2 equivalent per capita per year in 1994. Ethiopia's GHG emissions are mainly sourced from agriculture, which contributes up to 80% of the total emission of the country. In addition, the energy sector (heating, cooking, and transport) contributes about 15% of the total emissions where about 95% of the energy is sourced from bio-masses, petroleum and electricity (Figure 5). Ethiopia's GHG emissions are closely linked to the basic needs of population of the country like food production and heating.

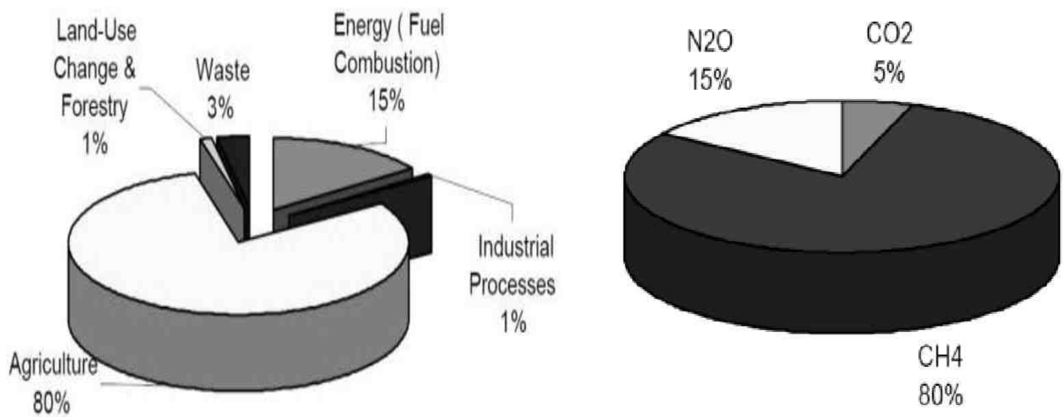

Figure 5. Total GHG emissions by sectors in Ethiopia and the relative contribution of individual greenhouse gases to climate change (NMSA, 2001)

4. Impacts of Climate Change on Crop Production of Ethiopia

4.1. Effects of climate change on agronomic activities

According to Adefris *et al*. (2013), crop production in Ethiopia is practiced during the rainy season as rain fed agriculture. Therefore, delay on the onset of rainfall hampers the regular land preparation activities and postpones the time of sowing or planting of crops. Drought also affects land preparation through either weakening or causing death of oxen that are used for tillage of croplands. Delay in onset and early cessation of rainfall forces the farmers to miss the optimum planting time of crops. As a result, farmers fail to plant long-season crops especially in semi-arid areas where the soils have mostly low water holding capacities. In this regard, Brohan *et al*. (2006) reported significant reduction of the growth and performance of long cycle crops of maize and sorghum due to poor performance of rain during the months of April and May.

4.2. Effects of climate change on opportunities to grow different crop types or varieties

Climate variability/change reduces opportunities of the farmers to grow different crop types or varieties in a given area. According to Yesuf *et al.* (2008), crops like fababean, lentil and wheat grown in the midlands are being replaced by sorghum, maize and haricot bean in response to declining and erratic rainfall distribution. Areas used for growing of chickpea, peas and long maturing sorghum varieties in Central Rift Valley are now growing medium or early maturing varieties of other crops because of early session of rainy season. Replacement of maize and sorghum over time by early maturing teff varieties as well as late planting of crops with lower total water consumption has been observed in most of the semi-arid regions of Ethiopia. Currently, maize and sorghum cultivars grown in Adama and Miesso areas are prone to the impact of water deficit, which results in the reduction of yields as indicated by Giorgis *et al.* (2006).

4.3. Effect of climate change on yields of crops

The most prominent impacts of climate change are reduction of crop yield. In severe cases, climate change may cause total failure of crop harvest. Irregular rainfall distribution affects the growth and development as well as the phenology of different crops. Moreover, occurrence of rainfall during the harvesting time may cause shattering of crop grains, pre-harvest seed germination and disturb harvesting operations. Due to the erratic rainfall distribution, up to 100% crop losses were recorded in various parts of West Arsi Zone of Oromia Region in different crop growing years (Adefris *et al*., 2013).

Based on the reports of Nelson *et al.* (2009), the yields of rice, wheat and maize have been reduced 15%, 34%, and 10%, respectively, due to the impacts of climate change in Sub-Saharan Africa. Similarly, the yield of maize has been reduced by 80% and 25% in Boricha and Metarobi lowlands, respectively, in southern part of Ethiopia because of shortage of rainfall during the months of March to May in 2004 growing season (Roach, 2005). Similar findings were also reported by Devereux (2006) who reported highly vulnerability of food production in semi-arid areas of Somali Region in Ethiopia.

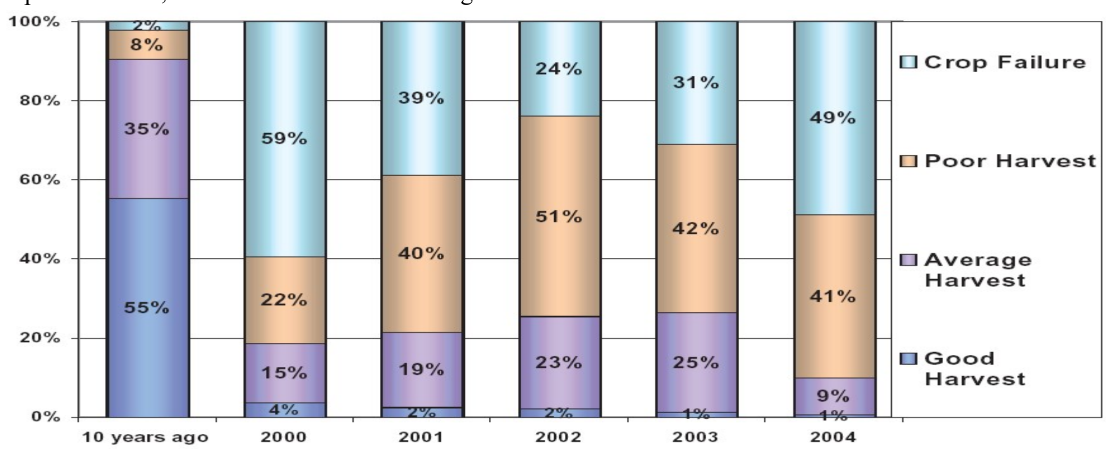

Figure 6. Crop harvest of Somalia Region in different years (1994–2004) (Devereux, 2006)

Generally, water availability is the most critical factor for sustaining crop productivity in rain fed agriculture as it greatly affects availability of soil water necessary for crop production and thus poses crop production risks. In this regard, Bewket (2009) has observed the relationships of rainfall distribution with yields of cereal crops in Amhara Region (Table 1).

The yield increment of teff was observed when the rainfall was increased from May up to August. However, the yield of teff was decreased due to the short rain. The yield increment of barley was observed during the rainy seasons including May, June, August and September. With regards to wheat, rainy seasons including May, July, August and September, maximizes wheat yield as compared to other rainy seasons. In these contexts, barley and wheat needs long rainy seasons. For maize, rainy seasons including May, July and August are the critical periods for maize production. With regard to sorghum, May and June are the critical periods for sorghum production. In addition, sorghum needs short rainy seasons as compared to other crops. According to Bewket (2009), the raining during the months of May, July and August are the most appropriate rainy seasons for millet production. Generally, different crops need different rainy seasons and their production depends on their respective rainy seasons (Bewket, 2009).

Similarly, Yesuf *et al.* (2008) reported negative anomalies in the production of teff, maize, sorghum and millet, which have been contributed to the low-average total cereal production in the region. The variability of water has been shown severe effects of sorghum, whose cultivation is dominated in the semi-arid and arid parts of the country which is prone to rainfall variability.

Table 1. Relationships between yields of cereal crops with monthly, seasonal and annual rainfall distribution in Amhara Region (Bewket, 2009)

Months	Teff	Barley	Wheat	Maize	Sorghum	Millet
May	0.137	0.444	0.506*	0.309	0.492	0.503
June	0.189	0.421	0.414	0.188	0.503	0.176
July	0.199	0.049	0.612*	0.345	0.079	0.224
August	0.623*	0.273	0.564*	0.349	0.260	0.236
September	0.493	0.348	0.733**	0.149	0.212	0.127
Belg (short rain)	-0.001	-0.24	-0.17	0.19	0.57	0.21
Kiremt (long rain)	0.47	0.43	0.80***	0.23	0.10	-0.005
Annual	0.26	- 0.35	-0.17	0.33	0.37	0.23

* = $p < 0.1$; ** = $p < 0.05$; *** = $p < 0.01$

5. Adaptation and Mitigation Strategies of Climate Change

5.1 Adaptation strategies

Adaptation is processes through which the societies make themselves better able to cope up with an uncertain future. Adaptation strategies entail taking the right measures to reduce the negative effects of climate change by making the appropriate adjustments and changes (UNFCCC, 2007). Accordingly, about 58% of the farmers in the Nile basin of Ethiopia are implementing some traditional adaptation measures to reduce the impacts of climate change that indicates the awareness of the farmers to change climates (Adefris *et al*., 2013). They are practicing different adaptation strategies including timing of various soil preparation operations and adjustments of frequency of tillage, selection of crop types based on soil moisture and slope, choose of the most suitable crop varieties and crop rotations and planting density, use of intercropping and other technologies to increase the efficiency of water use (Molla, 2009).

Moreover, the farmers have also introduced traditional irrigation and water harvesting schemes to cope with water stress during the growing period. Suggested adaptation strategies that can be implemented to improve crop production and productivity for possible climate change scenarios with the corresponding challenges/impacts are summarized in Table 2.

Table 2. Farm level climate change adaptation strategies for crop production in Ethiopia

Climate change related scenario	Challenge/impact	Adaptation options	Reference
Lack of seasonal rainfall (less than 250 mm)	Water requirements of crops cannot meet at any stage of growth, therefore crop production under rain-fed farming is impossible	Installation of irrigation scheme	Molla, 2009
Irreversible shift on onset of rainfall from early to late	Planting of long season varieties of crops cannot be possible	Planting of medium and or short season cultivars to fit the modified onset of rainfall	Bewket, 2009
Early cessation of rainfall	Length of the growing season of crops will be shortened, thus yield of crops will be reduced (e.g. shortened grain filling period, shriveled grain)	Implementation of water harvesting technologies for supplemental irrigation and increasing water use efficiency by using modern irrigation methods and mulching to conserve the available water. Implementing weather-based insurance scheme for climate risk management	Yesuf *et al.*, 2008
Soil water deficit as evaporative demand exceeds rainfall amounts	Crop production is possible, but rainfall is insufficient to meet crop water requirement	Implementing water harvesting technologies for supplemental irrigation at critical growth stages of crops and increasing water use efficiency by using modern irrigation methods. Mulching to conserve the available water and soil amendments to improve water holding capacity. Increasing water productivity (grain yield mm^{-1}) through cultivar choice and improving soil water management practices Implementing weather-based insurance scheme	Devereux, 2006
Unpredictable onset of rainfall extreme high rainfall	Difficult to practice the recommended agronomic operations (tillage, date of sowing, fertilizer use, etc)	Use of seasonal rainfall forecast information from National Meteorology Agency for early warning and use of the information from Bureau of Agriculture; implementation of weather-based insurance scheme	UNFCCC, 2007

Erratic distribution and extended dry spells after onset of rainfall	Reduction of crop yields or total crop failure due to shortage of moisture at critical stages of growth of crops	Implementing water harvesting technologies for supplemental irrigation at critical growth stages of crops and increasing water use efficiency by using modern irrigation methods. Mulching to conserve the available water and soil amendments to improve water holding capacity. Increasing water productivity (grain yield mm^{-1}) through cultivar choice and improving soil water management practices	Nelson *et al*., 2009
Torrential storms over a short time (days)	Rainfall exceeds infiltration capacity of the soil as result erosion, occurrence of soil born diseases, reduction of crop establishment and development	Establishment of drainage channels for safe disposal of excess water; development of varieties resistance to soil born diseases through breeding; harvesting excess water to be used during the times of water deficit	Deressa, 2006
Heat load	Premature switchover of the crops from vegetative to reproductive stage, occurrence of heat	Development of varieties that tolerate heat stress through breeding; irrigation to component evapo-transpiration losses	Giorgis *et al*., 2006

As Ethiopian crop production is highly dependent on rain fed, even short-term fluctuation in weather patterns significantly impacts the income of smallholder farmers. Loss of harvest could lead to loss of life. Within the current economic and technological constraints, farmers are usually barely adjusting to short-term climatic anomalies. In order to help the farming communities to cope better with climate variability and potential effects of long-term climate changes, the government of Ethiopia is trying to implement adaptation and mitigation strategies of climate changes through rigorous natural conservation practices (Bewket, 2009). Among the mitigation strategies practiced in the country, promotion of agro-forestry and afforestation, use of renewable energy sources, development of land use plan, promotion of conservation agriculture and use of organic fertilizer are the most important once (Molla, 2009).

Moreover, the government of Ethiopia is trying to improve the production and productivity of agriculture through polices of Agricultural Development Led Industrialization (ALDI), Growth, and Transformation Plan (GTP). Generation and implementation of improved crop production technologies have been done through these policies to raise the productivity of the agriculture sector and thus being self-sufficient in food production (World Bank, 2011). The Early Warning and Response Department (EWRD) have been also established under the Ministry of Agriculture and Rural Development (MoARD) with the aim of managing disasters. The EWRD; therefore, has developed a Disaster Risk Management Policies that attempt to directly reduce the impact of disasters (Adefris *et al*., 2013). However, more effort has to be done in developing and strengthening the institutional capacity of EWRD towards mitigation of the impacts of climate change.

Although there is availability of polices and strategies for adaptation and mitigation of climate changes, the program is constrained by various problems including lack of information about future climate change scenario, traditional farming practices, shortage of fund, poor irrigation infrastructures, lack of researches and poor extension services (Yesuf *et al*., 2008). Therefore, intensified investment in researches and extension services should be promoted that should be also linked with increasing farmer`s access to appropriate technologies, credit facilities and climate information as well as marketing and distribution networks (EARO, 2000). To this end, coordinated approach among governmental institutions and NGO is very important. Regular information exchanges and consultations would have to be organized between the respective stakeholders including National Metrology Agency, Ministry of Agriculture, extension services, NARS, and farmer`s unions and associations to monitor the current and future climate and environmental conditions of the country so as to establish an effective early warning system (Adefris *et al*., 2013).

5.2 Mitigation strategies

Currently, various mitigation options have been practiced in Ethiopia. Some of these include, promoting agro-forestry and afforestation, promoting conservation agriculture and organic soil fertilization, integrated waste management, improving the lad use, promoting the use of renewable energy, improving/promoting energy efficiency and conservation, promoting the use of fuels with low carbon content (fuel switching) (Molla, 2009).

Ethiopian farming is based on smallholder farmers and highly dependent on rain fed agriculture. Short-term fluctuations in weather patterns and, therefore, have significant impacts on farm income. A loss of harvest could mean loss of life. Within the current economic and technological constraints, usually farmers barely adjust to short term climatic anomalies. In order to help households and the farming communities better to cope with climate variability and potential long-term climate changes, government policies must address stagnation and under-investment in the agriculture sector, and the rapidly growing population has increased the ability of farmers to deal with shocks (Bewket, 2009).

The Economic Development Policy of Ethiopia has given the highest priority to agriculture under the aegis of an agriculture-led industrial development. Agriculture is already built into the Agricultural Development Led Industrialization (ALDI) and the Growth and Transformation Plan (GTP) and is the foundation for many of the other activities. In an effort to raise productivity of the agriculture sector and to be self-sufficient in food production, the government is focusing on generating and delivering technologies that will improve agricultural production (World Bank, 2011).

Most of the policies, strategies and development plans do not explicitly reflect climate change, although many of the proposed activities are directly aimed at reducing the impacts of drought. However, many of these programmes and policies encourage higher agricultural productivity through intensification. The Early Warning and Response Department (EWRD) have been established with a new institutional mission under the MoARD. The EWRD has already developed a Disaster Risk Management Policy for Ethiopia that attempts directly to reduce the impact of disasters (Adefris *et al*., 2013).

The availability of such policies and strategies is useful to develop the agriculture sector and improve disaster management. However, more effort is required in developing and strengthening of institutional capacity for mitigating the impacts of climate change. In this regard, intensifying investment in research and extension services to generate relevant technology and enhancing their immediate impact should be promoted. This should be linked with increased farmer access to appropriate technologies, climate information, measures to improve the marketing and distribution networks, and access to credit facilities (EARO, 2000).

While climate change will affect all sectors, it requires a coordinated approach among government institutions and NGO. Activities carried out by one ministry, agency or organization may contradict directly or indirectly with another and nullify one's effort unknowingly. Regular information exchanges and consultations would have to be organized between the weather forecasting stations, NARS, the agricultural extension service and farmer unions and associations. The NMA, Ministry of Agriculture, NGOs, and the NARS should effectively monitor current climate and environmental conditions in the country and establish an effective early warning system (Adefris *et al*., 2013).

6. Conclusion and Recommendations

Climate changes and their impacts in changing of weather patterns are already happening in Ethiopia while Ethiopia`s contribution to climate change is very limited. The negative impacts of climate change in the country are expressed in reduction of agricultural productivity and food insecurity, which will be exacerbated in the future. The impacts of the current climate variability on crop production have being clearly evident through the change in planting time of crops, length of growing season, crop types or cultivars grown in a given area, reduction of soil fertility and thus reduction of production and productivity of crops where food production is highly correlated with the rainfall patterns. Crop failure is also frequent during bad seasons.

Water harvesting for supplemental irrigation, improving water use efficiency by implementing modern irrigation methods and application of mulching materials and proper management of soil water as well as selection of appropriate crop types or cultivars and implementation of proper agronomic practices can be used as climate change adaptation strategies for crop production in Ethiopia. Moreover, climate change can be mitigated by rigorous natural resource management strategies including afforestation, promotion of agro-forestry, and use of renewable energy sources and development of land use plan.

Since, implementation of climate change adaptation and mitigation strategies are complex the following issues are recommended to improve production and productivity of crops in Ethiopia:

- Capitalize on the existing development policies and programmers and design short- and long-term action plans to implement adaptation and mitigation strategies;
- Increase research and extension services to generate data and technologies appropriate to adaptation strategies within the different agro-ecological zones;
- Improve the linkage and capacity of respective stakeholders including governmental organization and NGOs;
- Improve awareness and understanding of local communities about the relationship between climate change and crop production; and
- Improve the system of data collection, analysis and dissemination network to evaluate vulnerability to climate change and formulate decision support.

Conflict of Interest

The authors declare the absence of conflict of interest in publication of the manuscript.

References

Adefris, T., Girma, M., and Habtamu, A. (2013). Ethiopian Institute of Agricultural Research, Addis Ababa, Ethiopia.

Bewket, W. (2009). Rainfall variability and crop production in Ethiopia: Case study in the Amhara region. In: Ege S, Aspen H, Teferra B, Shiferaw B, eds. Proceedings of the 16th International Conference of Ethiopian Studies. Trondheim, Norway. P. 823–836.

Brohan, P., Kennedy, J.J., Harris, I., and Jones, P.D. (2006). Uncertainty estimates in regional and global observed temperature changes: A new data set from 1850. Journal of Geophysical Research Atmospheres 111: D12106.

Conway, D., Persechino, A., Ardoin-Bardin, S., Hamandawana, H., Dieulin, C., and Mahe, G. (2009). Rainfall and water resources variability in sub-Saharan Africa during the 20th century. Journal of Hydrometeorology 10: 41–59.

Central Statistical Agency. (2010). *Report on area and production of major crops. Vol. I. Bulletin No. 532*. Retrieved from http://www.csa.gov.et

Deressa, T., Rashid, M.H., and Ringler, C. (2008). Measuring Ethiopian farmers' vulnerability to climate change across regional states. Discussion Paper 00806. International Food Policy Research Institute.

Deressa, T. (2006). Measuring the economic impact of climate change on Ethiopian agriculture: Ricardian approach. CEEPA Discussion Paper No. 25, Centre for Environmental Economics and Policy in Africa, University of Pretoria.

Devereux, S. (2006). Vulnerable Livelihoods in Somali Region, Ethiopia. Institute of Development Studies Research Report 57.

Ethiopian Agricultural Research Organization. (2000). Dryland crops research strategy (DCRS). Addis Ababa, Ethiopia.

Federal Democratic Republic of Ethiopia. (2010). Growth and Transformation Plan (GTP) 2010/11–2014/15. Ministry of Finance and Economic Development (MoFED). Addis Ababa, Ethiopia.

Giorgis, K., Tadege, A., and Tibebe, D. (2006). Estimating crop water use and simulating yield reduction for maize and sorghum in Adama and Miesso districts using the Cropwat model. Climate Change Impacts on and Adaptation of Agroecological Systems in Africa. CEEPA Discussion Paper No. 31, Special Series on Climate Change and Agriculture in Africa and Vulnerability Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE, eds. Cambridge: Cambridge University Press.

Molla, M. (2009). Climate change and crop agriculture in Nile basin of Ethiopia: Measuring impacts and adaptation options. A thesis submitted to the school of graduate studies of Addis Ababa University in the partial fulfillment of the requirements for the degree of Master of Science in economics under natural resource and environmental economics stream. Addis Ababa, Ethiopia.

Nelson, G.C., Rosegrant, M.W., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, C., Msangi, S., Palazzo, A., Batka, M., Magalhaes, M., Valmonte-Santos, R., Ewing, M., and Lee, D. (2009). Climate Change Impact on Agriculture and Costs of Adaptation. IFPRI Food policy report.

National Meteorological Agency. (2007). Climate Change National Adaptation Programme of Action (NAPA) of Ethiopia. Report of the Federal Democratic Republic of Ethiopia, Ministry of Water Resources, and National Meteorological Agency. Addis Ababa, Ethiopia.

National Mission for Sustainable Agriculture. (2001). Initial National Communication of Ethiopia to the United Nations Framework Convention on Climate Change (UNFCCC). Addis Ababa, Ethiopia. (Available from http://unfccc.int/resource/docs/natc/ethnc1.pdf) (Accessed on 24 June 2013)

Roach, R. (2005). Dried up, drowned out: Voices from the developing world on a changing climate. Middlesex, UK: Tear Fund.

Schneider, U., Fuchs, T., Meyer-Christoffer, A., and Rudolf, B. (2008). Global precipitation products of the global precipitation center (GPCC). Deutscher Wetterdienst, Offenbach A. M., Germany.

United Nations Framework Convention on Climate Change. (2007). Climate change: Impacts, vulnerabilities and adaptation in developing countries, assessment report.

World Bank. (2011). Ethiopia: Climate risk fact sheet (Available from http://siteresources.worldbank.org/INTAFRICA/Resources/Ethiopia_Country_Note.pdf) (Accessed on 24 June 2013)

Yesuf, M., Di Falco, S., Deressa, T., Ringler, C., and Kohlin, G. (2008). The impact of climate change and adaptation on food production in low-income countries. Evidence from the Nile Basin, Ethiopia.