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A TIME SERIES ANALYSIS OF CLIMATE VARIABILITY AND ITS IMPACTS ON FOOD PRODUCTION IN NORTH SHEWA ZONE IN ETHIOPIA

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ABSTRACT

North Shewa is among the areas in Ethiopia hardest hit by climate change (CC), mainly through frequent occurrence of CC induced hazards like flooding, insect outbreaks, hailstorm, alien weeds, disease and pests, droughts and all others which are a result of CC. Time series data collected from the Central Statistical Authority of Ethiopia and the National Meteorological Agency of Ethiopia were employed to examine the variability in the trends of precipitation and temperature over the period of three decades. An attempt was made to measure the number of people and area of land vulnerable to CC induced shocks over a time scale. Also, estimation of the impacts of CC on food production was done using an econometric model; where climate variables together with other factors were set to be determinant of food production over time. The co-integrated Vector Auto Regressive and Error Correction Models were employed to empirically analyse the impact of CC factors on food production. The estimated results show that food production was significantly affected by improved technology, area under irrigation, manure usage, *Meher* rain and temperature, while fertiliser application and *Belg* rain were found to be less significant in the model. The Johannes' approach revealed that 90% of the variation in productivity was explained by area under irrigation, area covered by manure per hectare, the change in usage of improved variety, and the three climate parameters (*Meher* Rain, *Belg* rain and Average temperature).

Key Words: Climate change, Ethiopia, Johannes' approach, time series, Vector auto regression

RÉSUMÉ

Le Nord du Shewa en Ethiopie est parmi les régions les plus affectées par les effets du changement climatique (CC), comme les inondations, principalement par des catastrophes fréquents liés au CC comme les inondations, les infestations d'insectes, la grêle, les herbes envahissantes, les maladies, pestes, la sécheresse et autres conséquences dérivant du CC. Une série des données chronologiques collectées dans l'Office central de la statistique et l'agence éthiopienne de la météorologie était utilisée pour examiner la variabilités dans les tendances de la précipitation et la température au cours d'une période de trois décennies. Un effort a été fait pour déterminer le nombre de personnes et les entendues de terre affectées par les effets du CC au cours du temps. Aussi, l'impact du CC sur la production vivrière était estimé sur base d'un modèle économétrique où les variables-climat étaient intégrées comme déterminants de la production vivriere au cours du temps. Le Vecteur co-intégré Auto Régressif et les modèles dit de la Correction d'erreurs étaient employés pour l'analyse empirique de l'impact des facteurs du CC sur la production vivriere. Les résultats prédits montrent que la production vivrière est significativement affectée par la technologie améliorée, l'espace sous irrigation, l'utilisation du fumier, la pluie de Meher et la température alors que l'application d'engrais et la pluie de Belg sont moins signifiants dans le modèle. L'approche de Johannes a révélé que 90 % de la variation dans la productivité est expliquée par la superficie irriguée, la superficie couverte par le fumier par hectare, le changement dans l'utilisation des variétés de semences améliorées, et les trois paramètres climatiques (Pluies de Meher, pluie de Belg et la température moyenne). Les résultats prédits montrent que, alors que la production alimentaire est significativement affectée par l'amélioration de la technologie, sous irrigation, l'utilisation du fumier, la pluie de Meher et la température, l'application d'engrais et la pluie de Belg sont moins significatives dans le modèle. L'approche de Johannes a révélé que 90 % de la variation de la productivité est expliquée par la superficie sous irrigation, la région couverte par le fumier par hectare, le changement dans l'utilisation de la variété améliorée et les trois paramètres climatiques (pluie de *Meher*, pluie de *Belg* et température moyenne).

Mots Clés: Changement climatique, Ethiopie, Approche de Johannes, une série, Vecteur auto régression

INTRODUCTION

Climate change (CC) manifest in the form of temperature increases, changes in precipitation and sea level rise, and the intensification of natural hazards, such as storms, floods, droughts and landslides (IPCC, 2007). One major implication of global warming is greater scarcity and variability of renewable resources in many parts of the world (IPCC, 2001). Agriculture, being the main source of food, fiber and jobs; and farming activities being directly dependent on climatic conditions, it is highly exposed to the effects of CC. Though CC affects all countries globally, developing countries are the most vulnerable as they have inadequate resources to adapt. Ethiopia in particular and the horn of African in general have for the past decades experienced unprecedented food shortages due to CC (Toulmin *et al*., 2006). Due to adverse climatic impact, it is estimated that rain-fed crop yields could most likely drop by 50% by 2020; and net crop revenues could fall by 90% (IFAD, 2010). This inability to tap the full potential of agriculture threatens the attainment of Millennium Development Goals (MDG) and rolls-back many poverty alleviation programmes, thus leaving a sizable population in the core poor category.

In line with this fact, three out of four people live on less than US$ 2 per day in Ethiopia and the horn of Africa (IFAD, 2010). A number of factors has contributed and continue to account for this state of affairs, including hostile policy environments, weak production infrastructure, lack of modern farming techniques and more significantly, the changing of global climatic conditions. The IPCC (2007) report stated that global temperature is on the rise, with massive consequences, such as rising sea levels, drought, high winds, cyclones, and extreme temperatures, that would pose significant challenge to the lives and livelihood of the farming based society.

In the future severe climate scenarios are expected to occur frequently, with the prediction that, the amount of arid and semi-arid land in Sub-Saharan Africa is expected to increase by 5 to 8% by the 2080s (WVI, 2011). This aggravates the unfavorable land tenure situation in many parts of Africa. In Ethiopia where the national economy is dependent on sectors that are vulnerable to climate conditions, such as agriculture, fisheries, forestry and tourism, it is inevitable to have the adverse effects of CC. Dry spells and droughts will be more frequent, rain more inconsistent, and torrential downpours heavier, all phenomena that increase the risk of soil erosion and vegetation damage through runoff. This coupled with shortage of improved technology, low technical know-how, and poor marketing system resulted in serious food insecurity and economic underdevelopment of the country. Higher temperatures will increase the evaporation of soil moisture and this will aggravate water stress in cropping systems.

Climate extremes of particular significance to North Shewa in Ethiopia are variation in rainfall and associated drought and flooding. There is no sufficient research evidence on the impact of these changes on the national economic performance as well as local economic growth, except the recent attempt made by the unpublished work of Seid (2011). As far as literature is concerned, there have been limited research efforts (Deressa, 2008; Mahmud *et al.,* 2008; Woldeamlak *et al.,* 2011; Workineh *et al.,* 2011) to address CC perception and adaptation and its agricultural impacts. With this background, the objective of this study is to analyse the trends in the variability of climate condition as well as and the magnitude of CC induced natural shocks that damaged the livelihood of farm households.

METHODOLOGY

The study area. The study was conducted in the North Shewa Zone of Oromia regional state in Ethiopia. North Shewa Zone is located in the north-western direction of Addis Ababa. The zone is situated between $9^0$30N and $38^0$40E. The topography is ragged terrain with some mountains. The altitude ranges between 1300 and 2500 meters above sea level. It is divided into three agro-ecologies, namely, 15% Highland, 40% Midland and 45% Lowland (CSA, 2007). There are two rainy seasons, namely *Belg* (February - April) and *Meher* (June - September). The average annual rainfall ranges from 1400 to 1600 mm; while mean annual temperature varies between 15 and 19 ^{o}C.

Data collection and analytical. The study mainly depended on the review of secondary data at zonal level for the region. The relevant data were obtained from the National Meteorological Service Agency (NMSA), Central Statistical Authority (CSA), Zonal and district's agricultural offices. Such secondary data included socio-economic and demographic characteristics, including crop and livestock production, perennial crops production, local and improved input used, extension services, rainfall and temperature variability, types and frequencies of CC induced shocks, level of damage caused by natural hazards, and other relevant parameters used to measure CC impacts.

In order to verify the authenticity of the secondary data and support the results from the secondary data, a household level qualitative survey was carried out in February 2012. The data were collected through focused group discussions (FGD) using a checklist prepared for the purpose. The data collected were for experience of farmers on CC parameters, their perception, farming practices; history, frequency and intensity of CC induced shocks; damages farmers' faced annually; and households' coping mechanisms to natural shocks. In total, 18 rural peasant associations from highland, midland and lowland have participated in the FGDs.

The data collected were summarised and analysed using different analytical tools. The secondary data collected were summarised using descriptive statistics and then analysed using a time series regression analysis. Variability of rainfall was identified using coefficient of variability, and normalised rainfall anomalies. The trends and patterns of rainfall were depicted on a times series graph, which was normalised. Johansen's co-integration method of data analysis was used to identify the impact of CC and other variables on food production in the zone. The first step involved determination of the level of integration of the variables. This is commonly called testing for stationarity/non-stationarity of the series. Hence, the non-stationary variables were transformed into stationary series or combined in a specific way before econometric work was undertaken. In the cases where a variable was trend deterministic, it was transformed into stationary series by regressing the variable on time (with the residuals from such a regression forming a new variable which is trend-free and stationary).

The econometric model the dependant variable was productivity measured as the total production per hectare of land expressed in quintals. The overtime trends in average temperature (Av_temp), total *Belg* rain (Belg) and total *Meher* rain (Mehere) are used to account for the change in climate. In order to avoid possible misspecification of the model, other determinants of productivity including commercial fertilisation usage per hectare (fertiliser), land area covered by irrigation (irrigation), area under improved variety per hectare (seed), and area covered by manure (manure) are incorporated in the model.

As a precondition for the estimation of the co-integrating relationship between productivity and its determinants using Johansen approach, we first determine the level of integration (stationarity) of the variables. Next, the long run co-integrating equation is derived after the appropriate lag length of the corresponding VAR model is identified. Finally, the short run error correction model together with the long run adjustment indicator variable is specified.

Data obtained from the focus group discussion and interviews were processed using qualitative techniques to support the findings of quantitative analysis.

RESULTS AND DISCUSSION

Variability of climate parameters: precipitation and temperature. The North Shewa situation indicates higher level of rainfall variability over the last couple of decades (Table 1). As the data from the National Metrological Agency (NMA) shows the yearly average rainfall deceases over time. Table 1 clearly depicts that between the years 1980 to 1986 the average precipitation for *Belg* and *Mehere* seasons were 107.34 milliliter and 1085.64 milliliter, respectively; while after thirty years between the years 2007 and 2011, the average rainfall decreased to 83.03 milliliter and 747.33 milliliter for *Belg* and *Meher* seasons, respectively.

The relatively high plateau on which North Shewa is located ensures that the zone has a temperature ranging between 15 and 19 °C and moderate rainfall ranging between1400 to 1600 milliliter. However, rainfall is unevenly distributed throughout the year. For instance during the years, 1986, 1993, 1994, 1998 and 2008 the rainfall was 704, 491, 695, 444 and 600 milliliters respectively, on the other hand for the years 1984, 1985, 1988, 1991 and 1992, the rainfall was 1035.3, 1022.1, 1011.1, 1194 and 1179 milliliters respectively. There used to be two rainy seasons; the major rainy season being from June to September and the minor rainy season being from February to mid of April. However, according to the report obtained from zonal agriculture office, over the last few decades (from 1980 to 2011), the rainy season becomes only one. This leaves the remaining months almost dry. Hence, for most rain-fed crops, the growing season is only the major rainy season. Moreover, much of the area's socioeconomic life is dominated by the unpredicted onset and cessation of rainfall, and its amount. For instance, within the last 10 years, there has been only two years during which the area received relatively good *Belg* rain that could be used for crop production. Out of the total 13 rural districts of the zone, 9 districts have already stopped *Belg* season cultivation. These districts depend only on *Meher* season for crop production. During some of the years, the onset of rain was found to be too early, while during other years the rain delays unduly, thus disturbing the cropping calendar of the farmers. In general, the amount of rainfall received each season is continually decreasing from year to year to the extent that some of the crops can no more be adapted to the area. Table 1 above indicates the general trend in the decrease of the average amount rainfall received for three decades. For instance in 2007 and 2008, there was a total failure of *Belg* rain throughout the zone; and in 2010 there was relatively better *Belg* season rain in 4 districts.

Figures 1 and 2 show the average annual *Meher* and *Belg* rainfall at the different weather stations in North Shewa during 1980-2011 interpolated. From south (Sululta area) to north (Derra district) across the zone, there is evidence of a downward gradient of annual rainfall (generally above 1076.4 mm), and the lowest in Gohatsion and Derra in the north (generally below 868 mm). Moreover, the variability of rainfall over years has significantly increased between the year 1980 and 2011. The amount of rainfall received has become more irregular as well as the time of set on and cessation has become even variable.

The amount of rainfall received has shown continual reduction from year to year, creating more scarcity of precipitation over years. For instance, the average amount of rainfall received before 25 years is significantly higher than the amount of rain received during the last five years. Figures 1 and 2 show a downward sliding in the amount of precipitation over the last 3 decades.

The lower part of the curve in Fig. 2 indicates periods during which there was a complete failure

TABLE 1. Seasonal rainfall patterns of North Shewa in Ethiopia for the period of 1980-2011

Seasons	1980-1986	1987-1991	1992-1996	1997-2011	2002-2006	2007-2011
Belg rainfall	107.34	134.6	92.81	64.38	101.05	83.03
Meher rainfall	1085.64	858.57	917.42	903.3	899.13	747.33

Belg represents rainfall for the period February - April; *Meher* represents rainfall for June - September

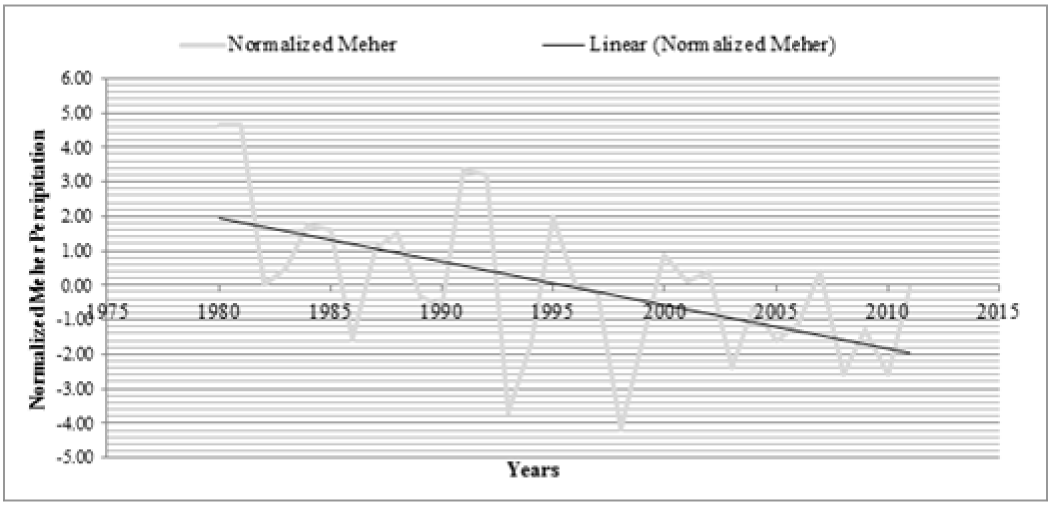

Figure 1. Normalised *Meher* season variability of rainfall from 1980 to 2011.

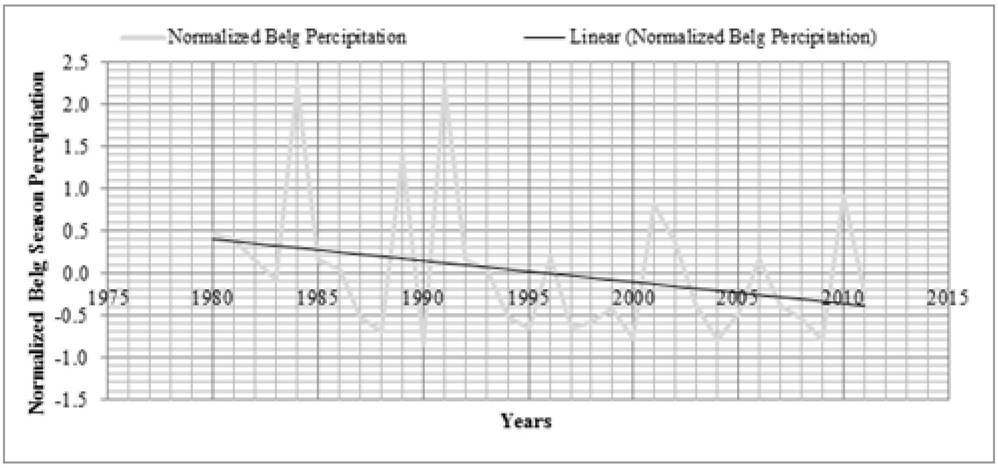

Figure 2. Normalised *Belg* season rainfall variability from 1980 to 2011.

of Belg season rain. According to the data from NMA and the report of North Shewa agriculture and natural resources offices, between the year 2007 and 2011, there was only one good *Belg* season's rain received by 4 districts of the total 13 districts. With the already evidenced *Belg* season failure, the comparison of the rate of decrease in annual precipitation between *Meher* and *Belg* seasons from the fitted linear lines of Figures 1 and 2 show higher rate of decrease for *Meher*, leaving the future to be more gloomy in allowing the production of current crop varieties.

When this is related to the global CC, the *La Nina* condition, which used to emerge every 30 years, has now come to emerge every year (UNOCHA, 2012). Meteorologists are blaming the drought on a *La Nina* event; a periodic shift in global precipitation patterns that, among other changes, can dramatically reduce rainfall in eastern Africa. In some areas, rains have failed for three or more consecutive rainy seasons, which normally occur between March and June and between October and December every year. The more significant rains of March to June (known as the 'long rains' in Kenya and 'belg' rains in Ethiopia) typically bring 40-80% of the yearly rainfall. Late, erratic and insufficient rains in these past months have tipped the region over the edge, following on the heels of one of the driest October-to-December seasons ever (Doreen, 2012).

According to the Park Williams and Chris Funk as cited by Doren (2012), to blame the drought on *La Nina* is to miss an important underlying cause; the slowly changing global climate that is drying out eastern Africa. There is a steady decrease in the region's long rains during the last 30 years (35-45% below normal), associated with the steady increase in sea surface temperatures of the Indian Ocean due to increasing global temperatures (Doren, 2012). Higher sea surface temperatures have led to changes in precipitation patterns so that rain now falls over the Indian Ocean rather than over countries like Ethiopia. For this reason, natural shocks under CC are expected to be more frequent and more intense; what scientists are calling 'global-change.'

For instance, for the 2012 *Belg* season which was supposed to come in February has not come yet across every areas of Ethiopia. The Ethiopian Meteorology Agency announced the amount of seasonal rain expected from the end of February to May would be late and below the regular in distribution this season in all areas receiving *Belg* rain. The Agency gave a press conference on February 9, 2012 in relation to the stated period's seasonal rain known as *Belg* rain, which has great significance for agricultural activities in south, south-east, east and north-east parts of Ethiopia.

Coldness of the sea level was mentioned by Dirriba Koricha to be among reasons for the weak rain during this season. Pre-warning and Forecast Director with the Agency urged farmers to make necessary preparations to cope with the possible shortage of rain for agriculture works in this season (ERTA, 2012).

On the other hand temperature variation appeared to be exhibiting significant change in the study area. Especially, variability became significant over the last couple of decades (Fig. 3). Apart from the observed high level of variability, the average temperature has continually increased over years, which has caused the shift in some of the crops from lowland to midland. Before 30 years, the average temperature ranged from 8.21 to 23.21°C; before 20 years, the average temperature ranged from 9.07 to 24.75°C; while in the last 10 years alone the average temperature ranged from 10.50 to 25.56°C. This clearly depicts the increasing trend in average temperature of the area.

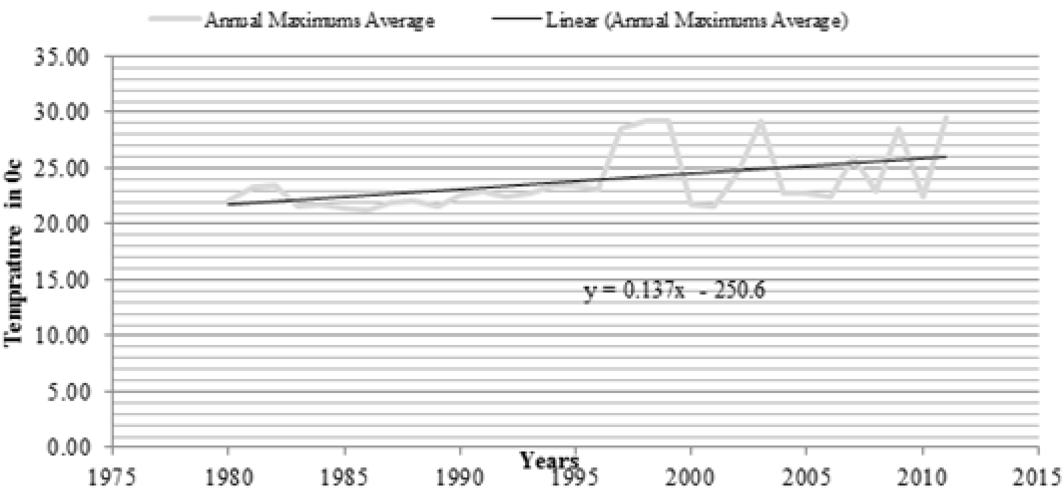

Figure 3. Actual and predicted trends and variability of maximum annual temperature North Shewa, in Ethiopia.

Figures 3 and 4 clearly show increasing trends in the minimum and maximum annual temperatures over a period of more than 30 years. Generally, the maximum temperatures increased faster than the minimum temperatures. Before 30 years, the relative pattern for temperature increase was steady and continuous with lower level of variability, whereas since 1994 onwards, the rate of increase and the level of variability increased dramatically, creating difficulty among the farming communities to predict temperature levels for the next year. In general, the temperature level increased temporally as shown by the fitted straight line with positive slopes.

Based on the last 30 years' data, it is possible to predict the temperature level for the next 10 to 20 years. Accordingly, from the year 2011 to 2021 it can be estimated that the average minimum and maximum temperature will range between 11.50 and 26.50 ^{o}C, respectively. Similarly, for the years between 2021 and 2031, the average minimum and maximum temperature is estimated to range between 12.50 and 27.56 ^{o}C, respectively.

Climate change induced shocks and crop damages

Community's disaster profile for the study area indicate that the major determinant factors that make community vulnerable to shocks include economic, physical, social and ecological factors. Apart from economic factors, the poor are in general far more vulnerable than economically better off sectors of the society. This is in relation to proportional higher losses when a disaster strikes as well as lower capacity to recover. Similarly, inadequate access to health facilities found to increase people's loss when exposed to both livestock and human epidemic diseases. The effect of location in terms of agro ecology also determines households' susceptibility to the risks; where people living in the highland areas are relatively very much vulnerable to risks of CC as compared to lowlanders. This basically emanates from the topography of farmlands, frequency of natural shocks, less experience of people to adopt to CC impacts, degradation of farmlands to erosion and more. Social factors like low level of literacy or lack of awareness on hazard related issues have been another bottleneck in the districts to easily recover from disaster impact.

Extreme weather events such as disease outbreaks, landslides, storms, floods and droughts, etc lead to crop shortfalls, the destruction of plantations and infrastructure, and an increase in the degradation of farmland in the area. Over a span of few decades, extreme meteorological events, such as spells of high temperature, heavy storms, droughts, and others have seriously disrupted crop production system of smallholder farmers. Recent evidences have shown possible changes in the variability as well as in the mean values of climatic variables. Where certain varieties of crops are grown near their limits of maximum temperature tolerance, heat

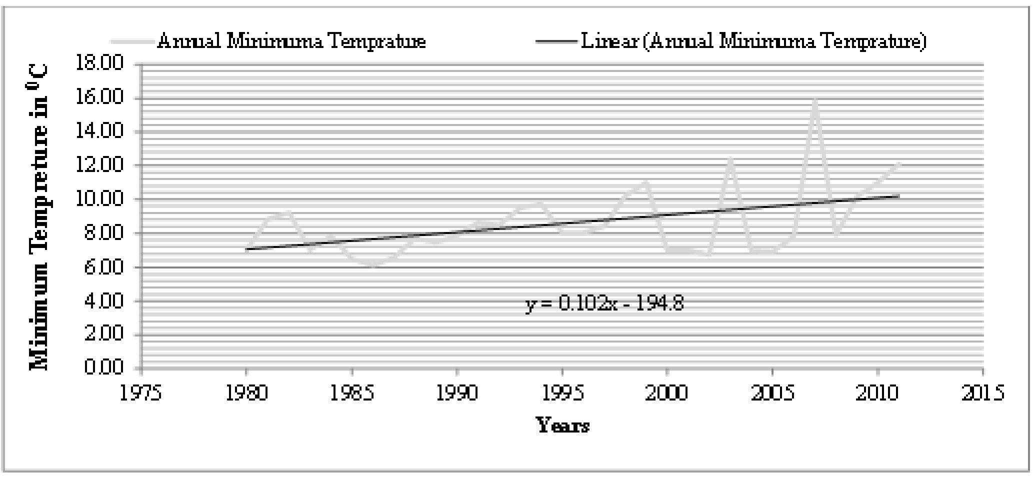

Figure 4. Actual and predicted trends and variability of annual minimum temperature North Shewa, in Ethiopia.

spells are becoming particularly detrimental. Similarly, frequent droughts especially in the low-lying regions not only reduced water supplies but also increased the amount of water needed for plant transpiration.

According to the data obtained from the district and zonal government offices of agriculture, the frequency of extreme weather events rose sharply over the previous three decades (Fig. 5). For instance, diseases outbreak that seriously affects potato, wheat, barley and other crops occurred every other year following early rain, with high temperature. In 2008 and 2010, the zonal office of agricultural and natural resource management estimated the damage to these crops to be >50% of the total production expected. What farmers alternatively did to sustain their living was to grow grass called wild oats, which was a weed before but now used as source of food, animal feed and source of cash.

Data obtained from the CSA for the last 10 years indicate that more than 3 million people were affected by the CC induced shocks. During the same period, crops over an area of 460,894.5 ha was damaged by flooding, insect outbreaks, hailstorm, alien weeds, disease and pests, droughts and others, all of which happen to be a result of CC. Of the total annual crop damage 5,

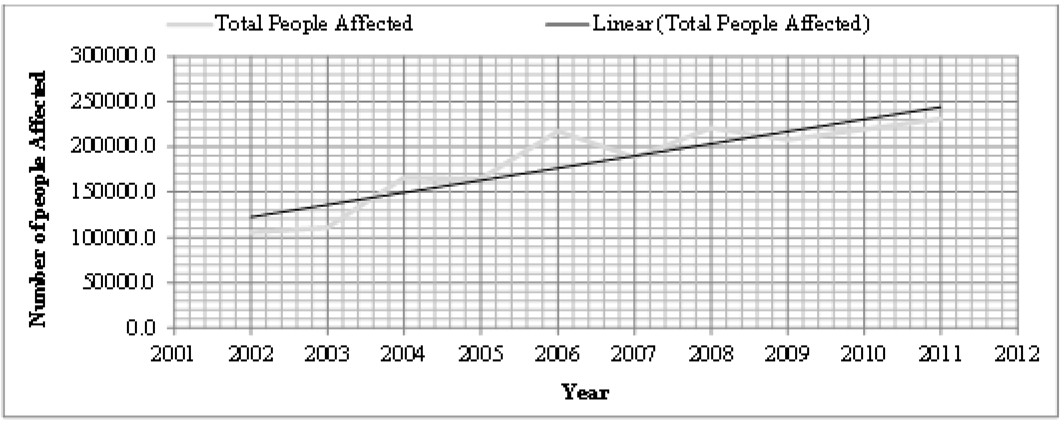

Figure 5. Trends and number of people affected by CC induced shocks in North Shewa, in Ethiopia.

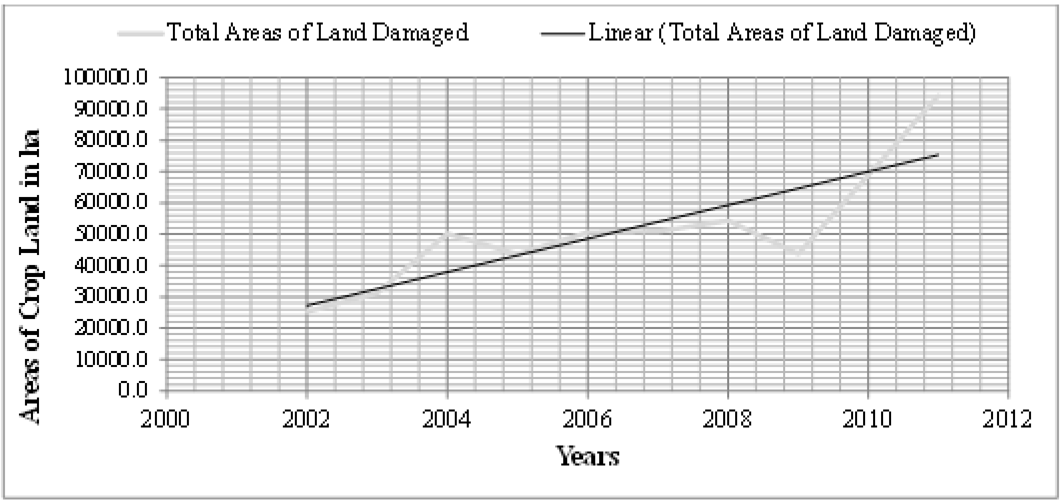

Figure 6. Areas of cropland damaged by climate change induced shocks in North Shewa, in Ethiopia.

3.38, 1.2 and 2.64% are attributed to flooding, hailstorm, insect outbreaks and alien weeds, respectively.

Figures 5 and 6 clearly depict the trends in the number of people affected and areas of crop damaged to CC induced shocks for 10 years. It is apparent that more and more number of people became vulnerable to CC impacts. For instance in 2002, less than 130,000 people were seriously affected by the combination of the above natural hazards, while in 2011 more than 240,000 people were affected by natural hazards. Similarly, the area damaged by natural hazard has increased from less than 28,000 ha in 2002 to more than 94,000 ha in 2011.

Over years, communities have used varieties of coping mechanisms that are sometimes positively and sometimes negatively affecting the following years' production capacity. According to the report of WVE (2010), the major coping strategies identified were sale of a liquid or productive asset, renting out their land, borrowing, labor wage, crop rotation, changing crop location, selling of household assets, and selling of natural resources so as to provide the household's basic necessities.

TABLE 2. Disaster history and trends in the last 15-20 years for North Shewa, in Ethiopia

Type of hazard/ disaster (from recent to past)	Cause of hazard	Month in year during which the hazards occur	Damage resulted	Most affected group of people	Actions taken
Flood	Heavy rain, deforestation	June-August	Death of animals, crop failures	Children, elders, disabled people	Provided livestock, seeds, and food
Drought	Deforestation, climate change	March-May	Shortage of food, Death of animals, crop failures ,and migrate	Children, elders, disabled and poor	Provided seeds, and food, selling charcoal and wood
Landslide	Natural	June-August	Death of animals, crop failures, and migration	Children, elders, disabled and poor	Community mobilized to plant trees

Sources: WVE (2010) community disaster preparedness Plan and Reports

Econometric estimation

Stationarity tests. Table 5 presents the results of the unit root tests on the level and first difference of all the time series variables used in the estimation. The results indicate that except for the three variables that indicate CC (*Belg*, *Mehere*, and Av_temp), which were stationary even before differencing; all variables were non-stationary and became stationary with first differencing and thus, are integrated of order I variables.

The fact that the time-series variables under consideration were non-stationary (i.e., I (1)) implies that the regression result using these variables in the classical framework leads to spurious regression, unless their linear combination produces a stationary residual (Gujarati, 2004). In the following subsection, we tested if linear combination of the I(1) variables was stationary using Johansen's multivariate approach.

TABLE 3. Number of people affected and crop area damaged to CC induced shocks in North Shewa, in Ethiopia from 2002 – 2011

S/N	Climate Change Induced shocks	Number of people affected in 10 years time	The average % of population affected (annually)	Total crop area damaged (ha)	% of affected area annually
1	Disease and pest outbreaks	168,265	1.2	22,926.311	1
2	Outbreaks of insect, migratory birds and wild animals	581,156	4.1	84,697.065	2
3	Frost, flood and too much rain	707,809	5	130,525.577	4
4	Droughts	130,718	1	8,965.836	0.2
5	Alien weeds	378,562	2.64	47,782.315	1
6	Hailstorm	483,635	3.38	93,193.991	3
7	Others (combination)	562,841	3.93	72,803.404	2
	10 years total	3,012,985	21.1	460,894.500	13

Long term co-integrating relationship. Using lag length of two as determined by the information criteria, Table 6 suggests that there was one co-integrating relationship between productivity and its three I(1) determinants: Irrigation, Seed and Manure (all variables are log transformed). The trace statistic for these variables at first difference is 29.67; which is significant at 5%. Thus, the null hypothesis of no co-integrating relationship was strongly rejected. However, the hypothesis of one co-integrating vector could not be rejected.

Therefore, though taken alone, the variables did not tend to revert to their long run equilibrium; the linear combination of productivity with the three variables did not stay away from the long run equilibrium relationship for too long. This long run equilibrium relationship is given in Table 7. It is clear from the Table that the three explanatory variables of the model were jointly significant at all conventional levels.

Table 7 presents co-integrating equation (_ce1) normalised relative to productivity. The first block of the table indicates that the three variables included in the model are jointly significant at all conventional level of significance. The second block of the table shows that while total area covered by manure and the area under irrigation are significant positive determinants of productivity in the long run, the total area under improved seed and fertiliser was not as such significant determinant for the north Shewa case for this specific data set. This appears to be contradicting the normal argument that technology is the primary determinant of productivity. This result is may be because of the fact that only small change (no significant variability) was observed in terms of improved seed usage and fertiliser application per hectare over years and the proportion of farmers using improved seed was also small with little change over years.

As the test for the goodness of fit, the model is checked for normality of the error term, serial correlation in the error term, and stability of the VEC model and the result in the annex shows that the model is well specified.

The short term error correction Model. The residual from the co-integration equation at lag one (ecm_1) together with the first difference of

TABLE 4. Climate change coping mechanisms identified in North Shewa, in Ethiopia

Types of hazards/disaster	Coping strategies	Season/ year
Flood	Browning money, Migrate,	Winter
Drought	selling fixed liquid asset, labor wage	Spring
Ice hazard	Replace by other crops, participate on off-farm activities	Winter

Sources: WVE (2010) community disaster plan and report

TABLE 5. Unit root tests

	in levels (log)		First difference	
Variables	Test statistic	P-value	Test statistic	P-value
Productivity	-1.74	0.409	-5.35	0.000
Belg	-6.34	0.000	-9.25	0.000
Meher	-7.61	0.000	-11.90	0.000
Av. Temp	-4.44	0.000	-11.52	0.000
Irrigation	-1.24	0.656	-4.81	0.000
Fertiliser	-2.17	0.507	-4.98	0.000
Seed	-2.51	0.326	-2.88	0.048
Manure	-2.00	0.600	-4.34	0.000

Note: The critical levels at 1, 5 and 10%, are respectively, -3.75, -3 and -2.63%

TABLE 6. Johansen multivariate test for co-integration

Trend: constant Sample: 1994 -2011				Number of obs. =18 Lags =2	
Maximum rank	Parameters	Lag length	Eigenvalue	Trace statistic	Critical alue (5%)
0	20	27.924	.	53.887	47.210
1	27	40.03	0.74	29.67	29.68
2	32	49.06	0.63	11.61	15.41
3	35	53.57	0.39	2.59	3.76
4	36	54.87	0.13	-	-

the three explanatory variables in the co-integrating equations (Dirrigation, Dmanure, & Dseed) at appropriate lag number defined by general to specific modeling are included to show the short run dynamics of productivity. Moreover, the three variables of CC indicators: total *Belg* rain, total *Meher* rain, and average temperature are included to capture the impact of the CC on productivity.

The results in Table 8 shows that more than 90% of the variation in productivity was explained by area under irrigation (Dirrigation), area covered by manure per hectare (Dmanure), the change in usage of improved variety per hectare (Dseed), and the three CC indicators. Specifically, in line with the theory, the Table indicates that improvement in agricultural technologies like irrigation and improved seed varieties played a

TABLE 7. Co-integrating equation

Equation	Parms	chi2	P>chi2		[95% Conf. Interval]	
_ce1	3	84.34303	0.000			
beta	Coef.	Std. Err.	z	P>z		
_ce1						
Productivity	1	.	.	.	.	.
Irrigation	-0.15	0.02	-6.35	0.00	-0.19	-0.10
Manure	-0.29	0.04	-7.71	0.00	-0.37	-0.22
Seed	0.21	0.18	1.22	0.22	-0.13	0.56
Cons.	-0.01	.	.	.	.	.

TABLE 8. Short run error correction Model

Source	SS	df	MS		No. of Obs.	17
Model	0.250323	9	0.028		F(9, 7)	24.77
Residual	0.007862	7	0.001		Prob > F	0.0002
Total	0.258185	16	0.016		R-square	0.9696
					Adj R-square	0.9304
					Root MSE	0.03351
Variables	Coef.	Std.Err.	t_stat	P>t	[95% Conf.	Interval]
Dirrigation						
L(0)	0.086	0.018	4.76	0.002	(0.043	0.129)
L(1)	0.209	0.022	9.41	0.000	(0.156	0.261)
Dmanure						
L(0)	0.309	0.038	8.06	0.000	(0.219	0.400)
Dseed						
L(0)	1.429	0.145	9.83	0.000	(1.085	1.772)
L(1)	-0.762	0.140	-5.44	0.001	(-1.093	-0.431)
Belg						
L(0)	0.008	0.011	0.77	0.467	(-0.017	0.034)
Mehere						
L(1)	-0.490	0.058	-8.4	0.000	(-0.628	-0.352)
Av_temp						
L(0)	-0.567	0.172	-3.31	0.013	(-0.972	-0.161)
ecm_1	-0.526	0.109	-4.84	0.002	(-0.783	-0.269)
Cons.	4.803	0.713	6.73	0.000	(3.117	6.490)

The parsimonious ECM is arrived at following a general to specific model reduction method positive role in improving productivity. It analogously shows that application of manure tends to boost productivity. More interestingly, the Table affirms the adverse role of CC on productivity. The Table further shows that change in *Meher* rainfall and the rise in average temperature had a productivity reducing effect; while the total *Belg* rain outturned statistically insignificant at all conventional levels.

Finally, error correction model (ecm_1) that represents the long run adjustment of the model after disequilibrium was significant. The coefficient of this term indicated that annually about 52.6% of the deviation from the equilibrium was adjusted back to equilibrium. This clearly proves the existence of strong co-integration, which in turn implies that there is a long run equilibrium relationship between our variables. Post-estimation tests indicate that the model is well specified and the residual is normally distributed, free from autocorrelation, serial correlation, and heteroskedasticity.

CONCLUSION

Food production in North Shewa faces severe challenges from CC. There are synergies between CC study and crop production analysis that can improve our understanding of long-term food security in the zone. This analysis integrates food production yield response to inputs, technical change, and CC factors. By combining both socioeconomic and environmental conditions in the analysis of food production, this study takes comprehensive approach to the issues of agricultural productivity and CC impacts.

Annual production losses to CC variability significantly increase from year to year. Especially in recent years, the number of people affected by CC induced shocks has increased to the level of 250,000 per year and crop area damaged to 100,000 ha per year. The most common type of disaster happening as a result of CC is flooding, insect outbreaks, hailstorm, alien weeds, disease and pest infestations and droughts. Before the year 1994, the total annual rainfall decreased slowly, while during the last 10 years rainfall variability has become very high and the annual precipitation decrease is also significantly high. North Shewa currently has one rainy season.

From time series analysis of agricultural food production over three decades, factors like improved technology usage, manure application, area brought under irrigation, improved seed per hectare, temperature, *Belg* rain and *Meher* rain were found to be most significant explaining 90% of the variation in food production. There is still great scope to increase yields by improving access to improved technology and irrigation. The empirical results provide evidence for future policy formulation to ensure a steady food supply through improved productivity and integrating climate change into long-term strategic planning.

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