GIS and Remote Sensing Based Assessment of Climate Change Impacts on Food Security: The Case of Central Rift Valley and Adjacent Highlands

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Abstract

The effects of climate change are severe in developing countries like Ethiopia where agriculture is the dominant economy. The Remote Sensing and GIS based analysis of climate change impact is crucial to help Ethiopia benefit the most from the technology. This study aims at assessing changes and variations in climatic elements in Central Rift Valley and adjacent highlands of Ethiopia where climate change has resulted in food insecurity. Thirty five years data analyzed from 22 meteorological stations indicate that temperature is rising by 0.37°C in the Central Rift Valley and by 0.48°C in the adjacent highlands every 12 years along with insignificant rise of rainfall in intensity.

Keywords: climate change and variability, food security, normalized maps, GIS, land use

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Introduction

Concerns about the effects of climate change are raised in international forums. They have also attracted the attention of country leaders and scientists around the world. Due attention has also been given to this issue because of occurrences of damage it might bring to the world following the change. It has become clear that not only have there been worldwide climate changes occurring in the last 100,000 years which have undoubtedly affected the distribution of crops and livestock but also that recent short term climatic change may be affecting agricultural distribution (Guy, 2003). According to a panel on climate change, potential climate changes in Africa would increase the global mean temperature by 1.5^0C to 6^0C by 2100. Different estimates indicate that there will be future warming across the continent ranging from 2^0C per decade to more than 0.5^0C per decade. For the IPCC mid-range (A1B) emission scenario, the mean annual temperature will increase in the range of 0.9^0C to 1.1 ^{0}C by 2030, in the range of 1.7 to 2.1 ^{0}C by 2050, and in the range of 2.7 to 3.4 ^{0}C by 2080 (MoWR and NMA, 2007:3).

Trend analysis of annual rainfall in Ethiopia shows that rainfall remained more or less constant when averaged over the whole country while a declining trend has been observed over the northern half of the country and south-western Ethiopia. Quoting IPCC, Sir Ericson wrote that annual rainfall is likely to decrease throughout most of the African region, with the exception of Eastern Africa, where annual rainfall is projected to increase. These changes in the physical environment are expected to have an adverse effect on agricultural production, including staple crops such as millet and maize.

Food Security and Climate Change

Natural disasters and climate variability are major sources of vulnerability for the food insecure. They particularly affect those in countries that largely depend on rain-fed farming and those highly dependent on agriculture. Poor people are also less able to cope with the impacts of climate shocks and variability. These events can result in massive crop losses, loss of stored food, and damage to infrastructure and consequent increases in food prices. Climate change is increasing the frequency and size of such events (POST, 2006:3). People who live on arid or semi-arid lands, in low-lying coastal areas, in water-limited or flood-prone areas, or on small islands are particularly vulnerable to climate change. It is clear that climate change will, in most parts of the world, adversely affect socio-economic sectors, including water resources, agriculture, forestry, fisheries and human settlements, ecological systems, and human health, with developing countries being the most vulnerable (IPCC, 2000). From the point of view of food security, the increasing incidence of drought represents a very serious threat. It has been argued that, in Africa, drought hazard and vulnerability are likely to be the most damaging locus of impacts of climate change (IPCC, 2000).

Food security in most of East Africa is not guaranteed through the market but through seasonal rain-fed subsistence farming. Eighty per cent of the population in the region depends on agriculture for a livelihood. Food security in most of East Africa is therefore intricately tied to climate variability and the predictability of planting and harvesting seasons. However, since 1996 there has been a marked variation in the amount of rain falling in the region as a result of climate change. This has in turn affected agricultural production, which has in turn affected food security (Mwebaza, 2009:11). Climate change will affect all four dimensions of food security: availability, accessibility, stability, and utilization. It will reduce food availability as it negatively affects the basic elements of food production – soil, water and biodiversity. This has direct effects on the quality and quantity of yields as well as the availability and price of food (WFP *et al.*, 2009:3).

Ethiopia is highly vulnerable to climate variability and change, due to its dependence on rain-fed agriculture, low level of socio-economic development, and limited disaster management skills. Quantitative climate impact assessments on Ethiopian agriculture are scarce (Belay Tseganeh *et al.,* 2010:1). Food insecurity in Ethiopia is persistently caused by a combination of factors that include recurrent drought which has increased in frequency of every 3 to 5 years; the flooding that has become more frequent in flood prone areas along the main river basins (WFP, 2009:7). Drought and famine, flood, malaria, land degradation, livestock disease, insect pests and earthquakes have been the main sources of risk and vulnerability in most parts of the country. Especially, recurrent drought, famine and, recently, flood are the main problems that affect millions of people in the country almost every year (MoWR and NMA, 2007:16).

Climate change poses an unprecedented challenge to the aim of eradicating hunger and poverty and meeting the growing demand for food security and nutrition under increasingly difficult climatic conditions and in a situation of diminishing resources (WFP *et al.,* 2009:7). Although the economic, social and environmental costs and losses associated with droughts and desertification have been increasing dramatically in the Horn of Africa, it is difficult to quantify their trends precisely because of lack of reliable historical estimates as a result of lack of systematic assessments, monitoring and recording and neither has there been systems that have specifically mapped the extent and trend of drought and desertification (Oroda, 2001:66).

GIS and Remote Sensing Applications in Assessing Climate Change Impacts

Recent studies showing the importance of spatial variables in tackling poverty have promoted the use of poverty maps made within a Geographic Information System (GIS) environment to better understand who the poor are, where the poor are found and to some extent, why and how long they have been poor. Consequently, decision makers can better identify and understand from maps, the socio-economic and development variations among regions for planning purposes. This makes poverty maps invaluable tools for poverty reduction especially in their use for targeting poverty alleviation programmes (Akinyemi, 2008:1).

A GIS framework provides an enhanced ability to assess the possible responses from a range of adaptation strategies to climate change by integrating the outputs from global circulation models and various modelling efforts in agriculture (Liua *et al.,* 2009). The key to understanding our dynamic climate is creating a framework to take many different pieces of past and future data from a variety of sources and merge them together in a single system. GIS creates a new framework for studying global climate change by allowing users to inventory and display large, complex spatial data sets. They can also analyze the potential interplay between various factors, getting us closer to a true understanding of how our dynamic climate may change in the coming decades and centuries (ESRI, 2008). Remote sensing is also suggested as an excellent tool for detecting climate change.

Significance of the Study

Ethiopia currently faces various environmental troubles resulting from climate change effects even though the degree of the damage is not precisely identified and quantified profoundly. The frequency and rate of the occurrences of climatic hazard is increasing. Variable climate situation, adverse and extreme events, recurrent drought, unseasonable rain, displaced rainfall intensity and food insecurity are continuously reported from Ethiopia as the prevailing problem. Currently climate vulnerability which was previously limited to semi arid regions of the country is expanded to the highlands as significant human intervention is prevailing in the highland ecosystem

Variations that occur in small scale have severe impact on human and natural environment. Drought occurs in many parts of the world but it is likely to happen in places where the climate is dry and changeable. As a result food insecurity problem is deepening its root from time to time even in areas where food aid was never known before and the districts from highland areas are suffering from food security problem. The changes detected through satellites bring in perfect interpretation and advanced approaches to overcome the problem. Technological advancements developed in due course make the problems to be studied easily through complicated analysis and models.

Objective of the Study

The over all study objectives are to examine, quantify, map and compare the degree of climate change and variability in parts of central rift valley and adjacent highlands and to assess its impacts on food security.

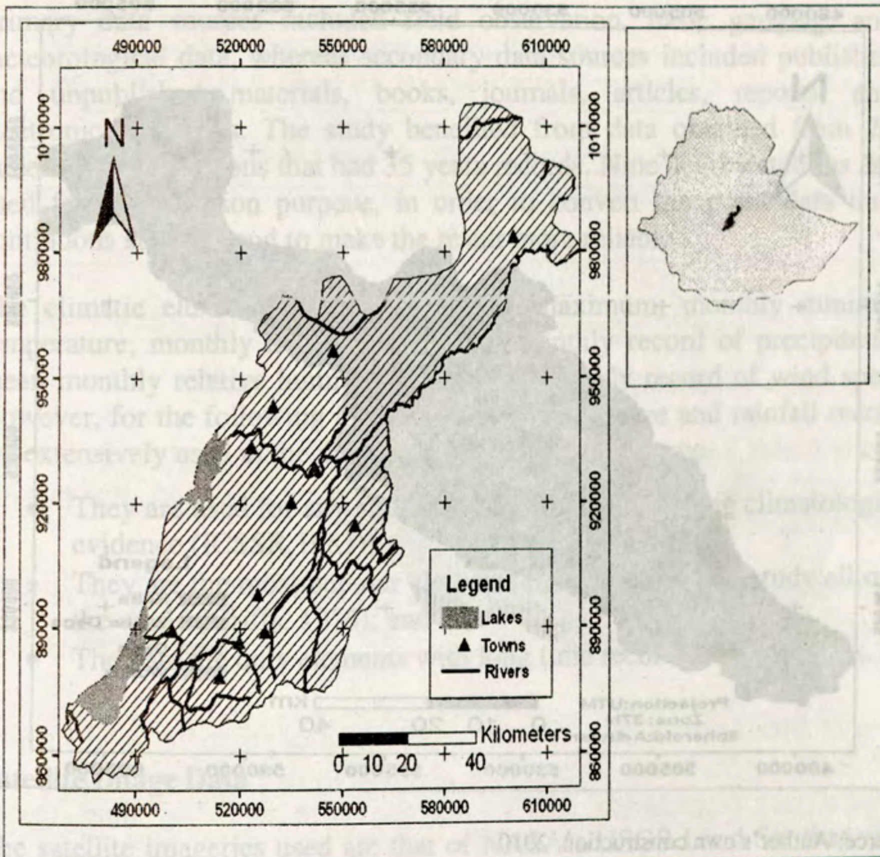
Methodology

The Study Area

The study area is found between $7^0$43'25''N-$9^0$11'01''N latitude and $38^0$43'07" E-$40^0$5'29''E longitude with a total area of 7758.3 km^2 as shown in Figure 1. The study area encompasses four ecological zones. The altitude ranges from lowest and the driest point found in the Fentalle lowland (789m) to the highest alpine of Chilalo Mountain (4135m) found in Arsi Zone. The rainfall ranges from 543mm in Metehara to 1300mm in Chilalo Mountain. Mean temperature of the study area ranges from 14^0C in Asella to 25^0C in Metehara. The area is selected due to its dynamismand it is believed to represent the climate change of the whole country since it contains all climate zones found in Ethiopia. Figure 1 below shows map of the study area.

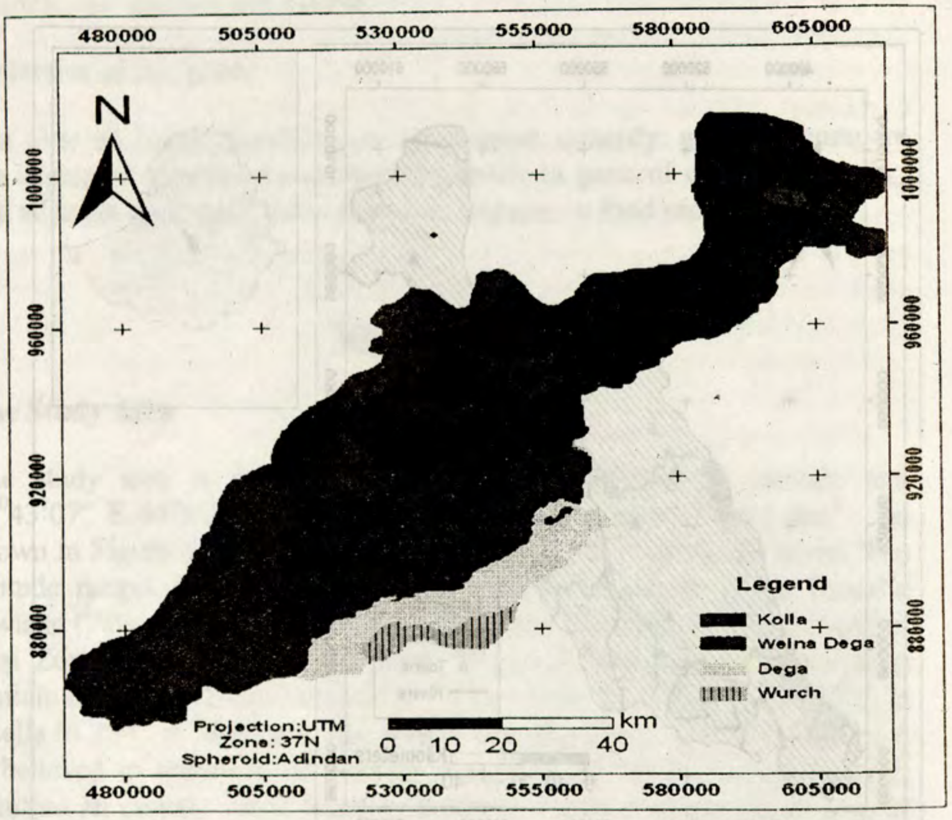
The long rainy season in the summer (June– September; summer monsoon rainfall, locally known as '*kiremt*') is primarily controlled by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ) which lies to the North of Ethiopia. The FAO classification of the soils in the study area indicates that large part of the area is covered by andosols and leptosols. Luvisols are also confined in the mountainous region of study area. Climate zone map is described in Figure 2.

Figure 1. Map of the study area



Source: Author's own construction, 2010

Figure 2. Climate Zone Map



Source: Author's own construction, 2010

Population and Economy

According to the 2007 census, the population in the study area was 1,420,900 with average population density of 197 per km^2. In 2007 population density ranged from 77 persons per km^2 in Fentalle to 346 persons per km^2 in Adama district. The largest groups of population in the study area earn their living from agriculture that includes both crop farming and livestock rearing.

Data Type and Source

Primary data sources included field observation, basic gauging, and meteorological data, whereas secondary data sources included published and unpublished materials, books, journals, articles, reports, and electronic web sites. The study benefited from data obtained from 22 meteorological stations that had 35 years records. Nine nearby stations are used for interpolation purpose, in order to convert the point data into continuous surfaces and to make the result more reliable.

The climatic elements used are monthly maximum, monthly minimum temperature, monthly mean temperature, monthly record of precipitation, mean monthly relative humidity and mean monthly record of wind speed. However, for the following major reasons, temperature and rainfall records are extensively used in the interpretation of climate change.

- They are used for any significant change in obtaining climatological evidence (ICSSR,1983);
- They are the most popular elements in climate change study all over the world (Griffs, 1976); and
- They are the only elements with long time records in the stations.

Satellite Image Data

The satellite imageries used are that of NASA's/USGS Land Sat that were acquired in 1973, 1986 and 2009 (Table 1). These satellite images are used specifically for land use and land cover change that especially emphasizes on forest cover change that can have significant effect on climate variability and climate change.

Table 1. Spectral characteristics of satellite images

Sensor	Number of spectral bands	Spatial Resolution(m)	Date of acquisition
MSS	4	80	Jan 30, 1973
TM	6	30	Jan 21, 1986
ETM	7	30	Jan 2, 2009

Source: Author's own construction based on LANDSAT image, 2010

Shuttle Radar Topographic Mission (SRTM) with 30m spatial resolution is also used. The SRTM provides the 3D view and the topographic characteristics of the study area.

Agricultural hazard data: recorded data of damaged land (due to climate change) per hectare since 1994 for some districts in Arsi and East Shewa zones.

Data of beneficiaries: the number of beneficiaries receiving food support from each district of the study area is obtained from disaster prevention and preparedness commission (DPPC) website even if it has short record history.

Methodology Used for Calculating Climate Change Impact Index

The methodology used to calculate the climate change impact index follows the basic approach developed by Anand and Sen, 1994 for the calculation of the human development index (HDI). To construct the vulnerability index for the districts, the steps described below are used.

Step 1: Calculate a dimension index of each of the indicators for a district (X I) by using the formula (Actual X I – Minimum X I) / (Maximum X I – Minimum X I)

Step 2: Calculate the average index for each of the selected sources of vulnerability.This is done by taking a simple average of the indicators in each category.

Average Index i= [Indicator 1 +………. + Indicator J] / J

Step 3: Aggregate across all the sources of vulnerability using the following formula.

$$\text{Vulnerability Index} = [\sum_{i=1}^{n} (\text{Average Index}_i)^{\alpha}]^{1/\alpha} / n$$

Where,

J = Number of indicators in each source of vulnerability
n = Number of sources of vulnerability (in the present case n = α)

After the values of the index are calculated for all the districts, a ranking of the various districts can be carried out to identify the most vulnerable districts in terms of the indicators used for measurement.

The next step is classifying the results. Ordinary classification of the indices by equal interval might be used. But for a meaningful characterization of the different stages of vulnerability, suitable fractile classification from an assumed probability distribution is used. A probability distribution which is suitable for this purpose is the Beta distribution, which is generally skewed and takes values in the interval (0, 1), developed by Iyengar and Sudarshan in 1982 (ICRISAT, 2009:17). This distribution has the probability density given by

$$f(z)=\frac{z^{a-1}(1-z)^{b-1}}{\beta(a, b)}, \quad 0<z<1 \text{ and } a,b>0$$

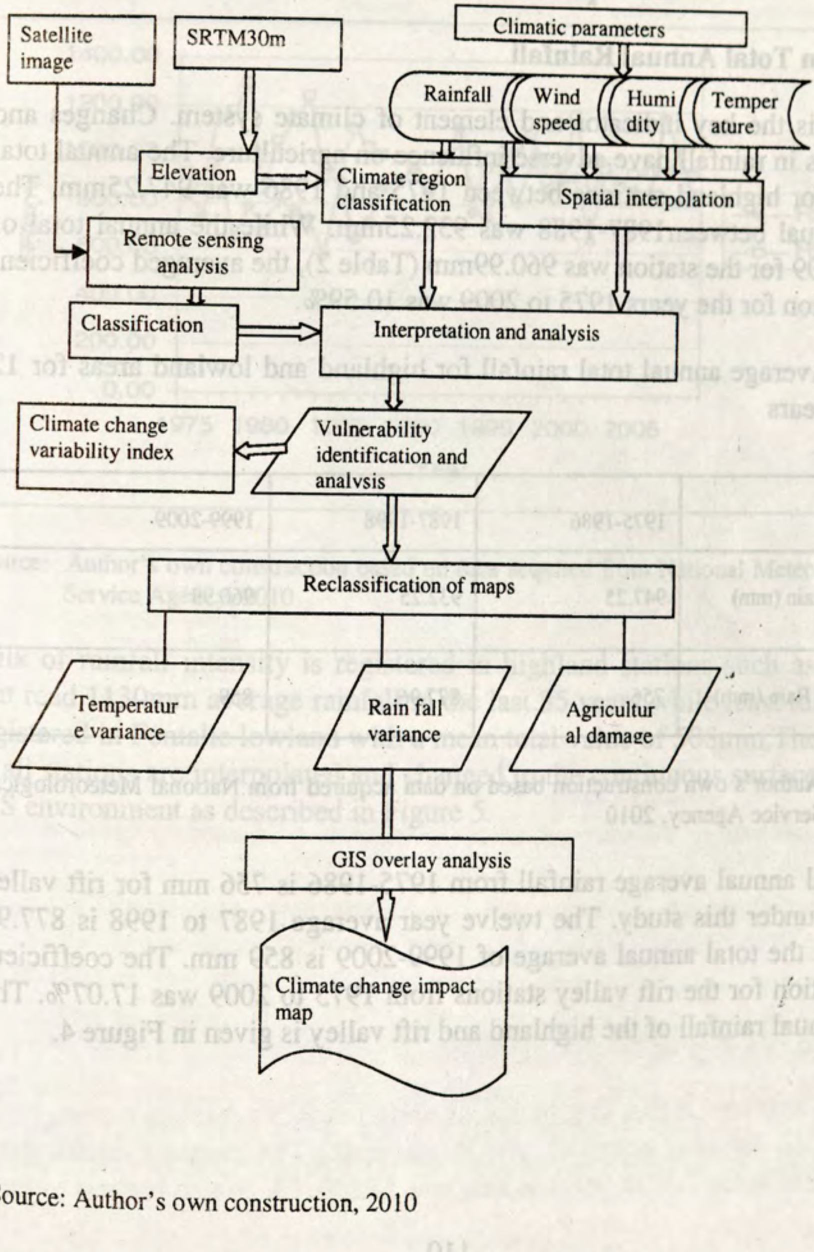
Where $\beta(a, b)$ is the beta function defined by

$$\beta(a, b)=\int_0^1 x^{a-1}(1-x)^{b-1}dx$$

Tools and Softwares

There are various image processing softwares developed for calculating climate change. These include ERIDAS IMAGINE9.2, ARCGIS9.3, Global mapper, 3DEM, EASY GPS and ENVI. Spatial and Geostatistical tools were used for data processing, analyzing and interpreting the result.The general flowchart of the study is described in Figure 3.

Figure 3 General methodology flowcharts



Source: Author's own construction, 2010

Interpretation and Analysis

Trends in Total Annual Rainfall

Rainfall is the key indicator and element of climate system. Changes and variations in rainfall have adverse influence on agriculture. The annual total rainfall for highland stations between 1975 and 1986 was 947.25mm. The total annual between1987-1988 was 932.25mm. While the annual total of 1999-2009 for the station was 960.99mm (Table 2), the averaged coefficient of variation for the years 1975 to 2009 was 10.59%.

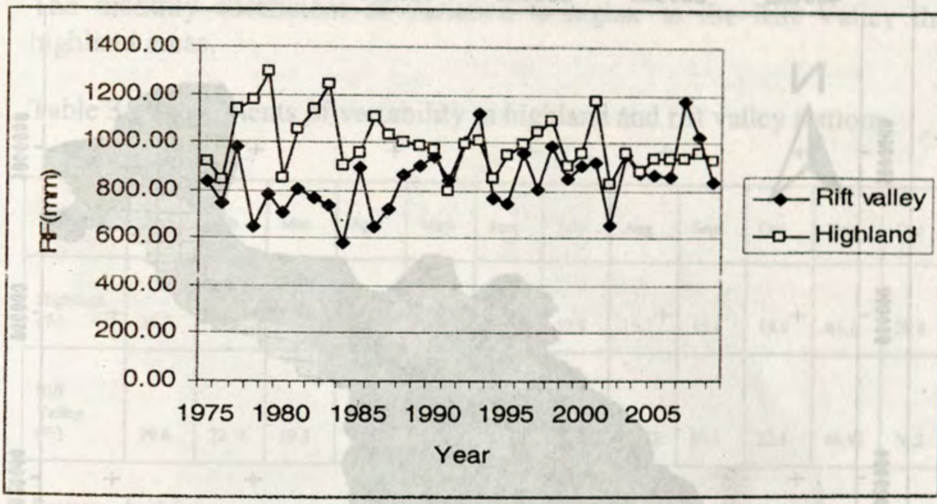
Table 2. Average annual total rainfall for highland and lowland areas for 12 years

Year	1975-1986	1987-1998	1999-2009
Highland Rain (mm)	947.25	932.25	960.99
Rift Valley Rain (mm)	756	877.96	859

Source: Author's own construction based on data acquired from National Meteorological Service Agency, 2010

The total annual average rainfall from 1975-1986 is 756 mm for rift valley regions under this study. The twelve year average 1987 to 1998 is 877.96 mm and the total annual average of 1999-2009 is 859 mm. The coefficient of variation for the rift valley stations from 1975 to 2009 was 17.07%. The total annual rainfall of the highland and rift valley is given in Figure 4.

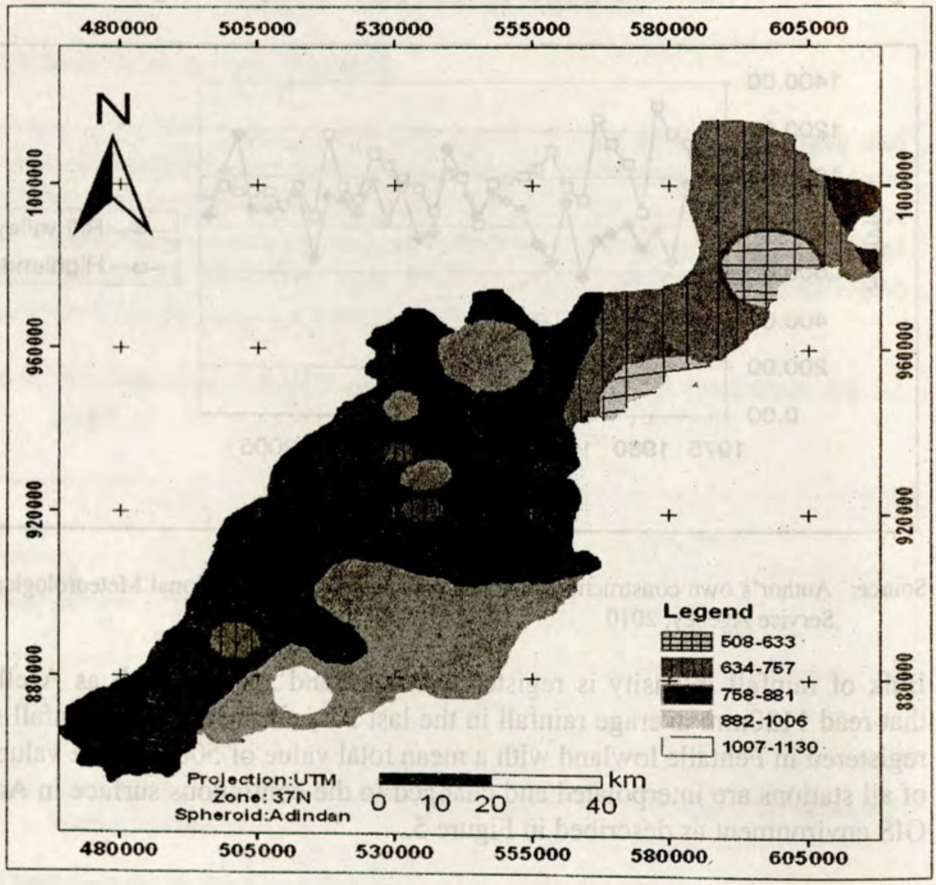
Figure 4. Total annual rainfall trends in the Rift Valley and highland areas



Source: Author's own construction based on data acquired from National Meteorological Service Agency, 2010

Bulk of rainfall intensity is registered in highland stations such as Asella that read 1130mm average rainfall in the last 35 years while least rainfall is registered in Fentalle lowland with a mean total value of 508mm.The values of all stations are interpolated and changed to the continuous surface in Arc GIS environment as described in Figure 5.

Figure 5. Reclassified rainfall map (1975-2009)



Source: Author's own construction based on data acquired from National Meteorological Service Agency, 2010

Trends in Coefficients of Variation

In the highland areas, coefficient of variation (CV) reaches a peak in July when all farming activities are at the peak. The average coefficient of variation in the last 35 years in July was 57.9%. CV is also highest in the months of December and January, when harvesting activity reaches the peak. In lowland stations the highest CV value is 68%, recorded in September and the lowest is about 15% which is recoded in July (Table 3). The monthly coefficient of variation is higher in the Rift Valley than highland areas.

Table 3. Coefficients of variability in highland and rift valley stations

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Highland (%)	35.7	36.9	21.1	16.4	20.5	20.3	57.9	15.7	15.4	19.6	41.1	28.8
Rift Valley (%)	29.6	22.76	19.3	20.5	9.96	22.9	14.36	25.45	69.5	22.4	48.92	36.2

Source: Author's own construction based on data acquired from National Meteorological Service Agency, 2010

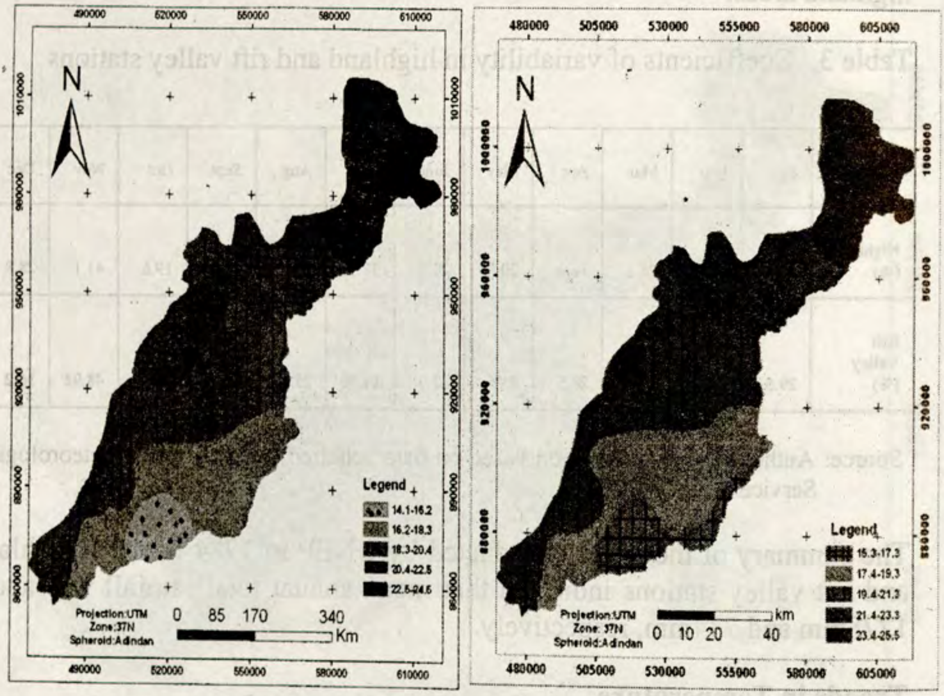
The summary of the survey conducted by UNEP in 1984 for both highland and rift valley stations indicated that mean annual total rainfall was about 1278mm and 734mm, respectively.

Trends in Temperature

Mean temperature of the study area varies from 15.3°C in highland areas to 25.5°C in arid lowlands. Mean temperature value from 1975 to 1986 was 21.20°C while mean temperature for the years 1987 to 1998 was 21.72°C and the temperature between 1999 and 2009 was 21.94°C for places included in the study area. The reclassified mean annual temperature is depicted in Figure 6. In 1975 the mean annual temperature was about 21.3°C and it grew to 22.9°C in 2009. Highland areas have an average annual temperature of 16.99°C on average, i.e., 16.37°C from 1975-1986, 17.36°C from 1987-1998 and 17.26°C from 1999-2009. The survey conducted by UNEP in 1984, for the stations since their establishment to

1984, shows that the highest mean temperature was 24.6°C and the lowest was 14.1°C in the study area as depicted in Figure 6.

Figure 6. Reclassified mean temperature map

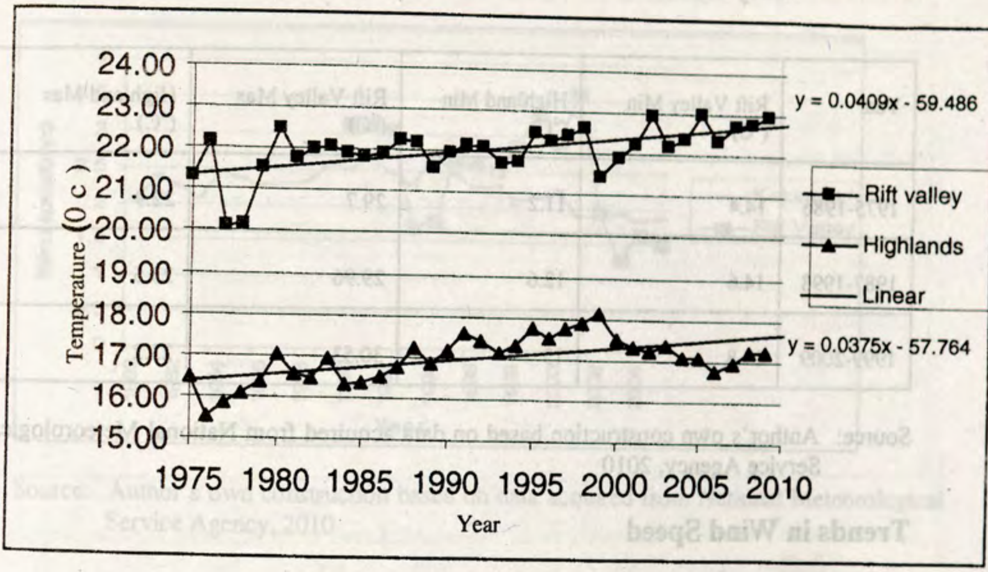


a) Mean temperature till 1984 b) Mean temperature (1975-2009)

Source: Author's own construction based on data acquired from National Meteorological Service Agency, 2010

The highland regions experienced sharp rise in temperature between 1995 and 2000 with the highest temperature record of 18.11°C in 1999. The lowest temperature (15.5^{0}c) was recorded in 1979. The mean annual temperature rise of both highland and lowland areas is indicated in Figure 7.

Figure 7. Mean temperature rise (1975-2009) in highland and lowland areas



Source: Author's own construction based on data acquired from National Meteorological Service Agency, 2010

The average maximum temperature of the past 35 years was 23.2°C and 30.08°C in highland and lowland areas, respectively. The average minimum temperature was 12.2°C and 14.6^{0}c in highland and lowland areas, respectively. Maximum and minimum temperature from 1975-2009 is presented in Table 4.

Table 4. Maximum and minimum temperature of highland stations and rift valley areas

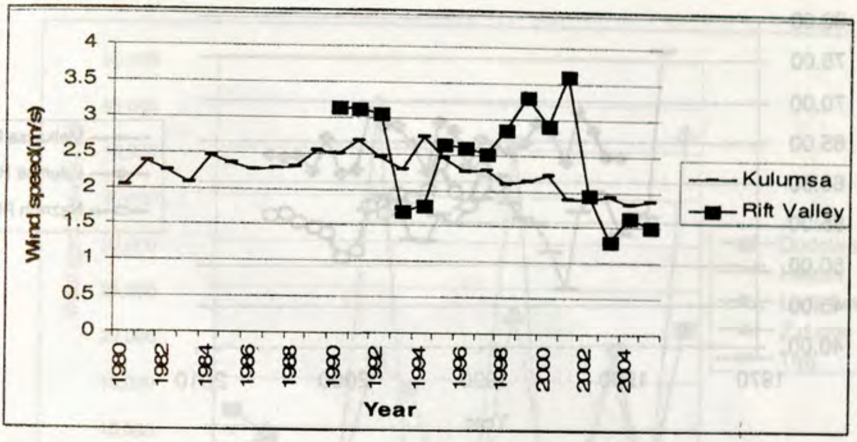
Year	Rift Valley Min (°C)	Highland Min (°C)	Rift Valley Max (°C)	Highland Max (°C)
1975-1986	14.4	11.2	29.7	22.9
1987-1998	14.6	12.6	29.96	23.5
1999-2009	14.8	13	30.53	23.2

Source: Author's own construction based on data acquired from National Meteorological Service Agency, 2010

Trends in Wind Speed

There is limited record of wind speed in the region. The highest record of wind speed prevailed in parts of the Rift Valley area is in the months of February and January with average wind speed of 3m/s and 3.25m/s respectively while the lowest wind speed (1.67 m/s) was registered in September. Wind speed reached its maximum in 2000 and 2001. The average wind speed for the past 15 years in the Rift Valley is 2.15m/s. The average wind speed for the highland area is acquired only from Kulumsa Station which only has a record of wind speed since 1980. The average wind speed for this station is 2.25m/s. The highest wind speed is registered in the months of November and October with an average speed of 2.97m/s and 2.65 m/s, respectively. The lowest wind speed is registered in September and August with average speed of 1.29m/s and 1.7m/s respectively. Temporal average wind speed variation of wind speed of rift valley and adjacent highland areas is given in Figure 8.

Figure 8. Temporal average wind speed variation for rift valley and highland stations



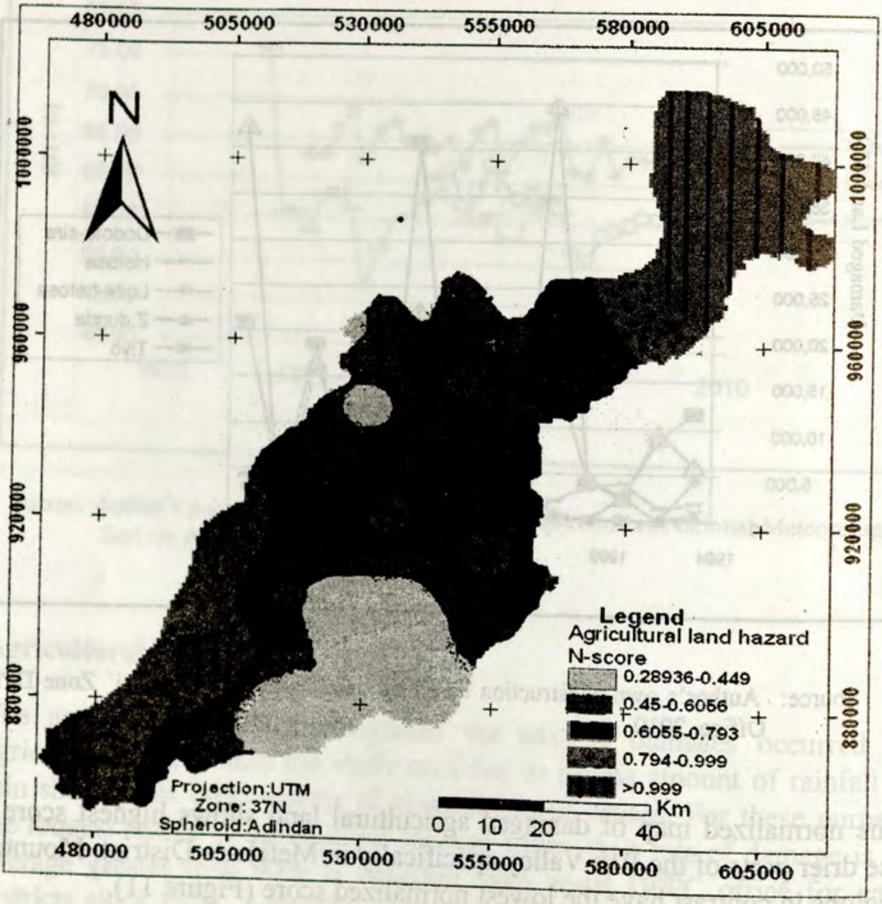
Source: Author's own construction based on data acquired from National Meteorological Service Agency, 2010

Trends in Relative Humidity

Relative humidity (RH) is a term used to describe the amount of water vapour that exists in a gaseous mixture of air and water vapour. The relative humidity in the study area doesn't show significant change in lowlands. The Melkassa station has 56.56% mean RH for the periods 1971-1999; the lowland areas have an average RH of 56.71%. The only record used in this research in highland area is that of Kulumsa with the record since 1980. The result shows that from 1980-1992 the average annual RH for the station is 64.76% and this value decreased to 64.26% in the consecutive thirteen years till 2009.

The three times record per day shows that highest RH is recorded at 6 Local Sideral Time (LST) that reaches about 75% and lowest at 1800 Local Sideral Time about 45% for rift valley areas. There is insignificant variation for this area. Mean relative humidity value averaged from Melkassa, Kulumsa and Nazareth stations is shown in Figure 9.

Figure 11. Normalized map of agricultural damage

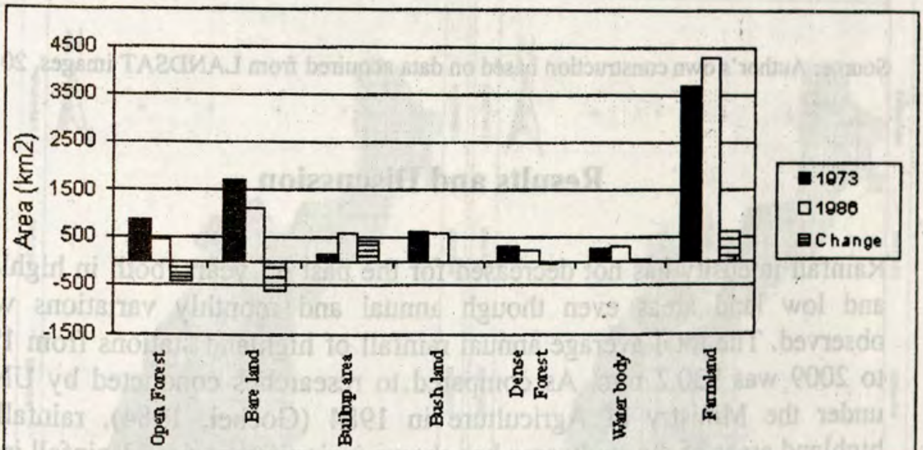


Source: Author's own construction based on data acquired from DPPC offices of East Shewa and Arsi Zone, 2010

Land Cover Change, Climate Change and Food Security

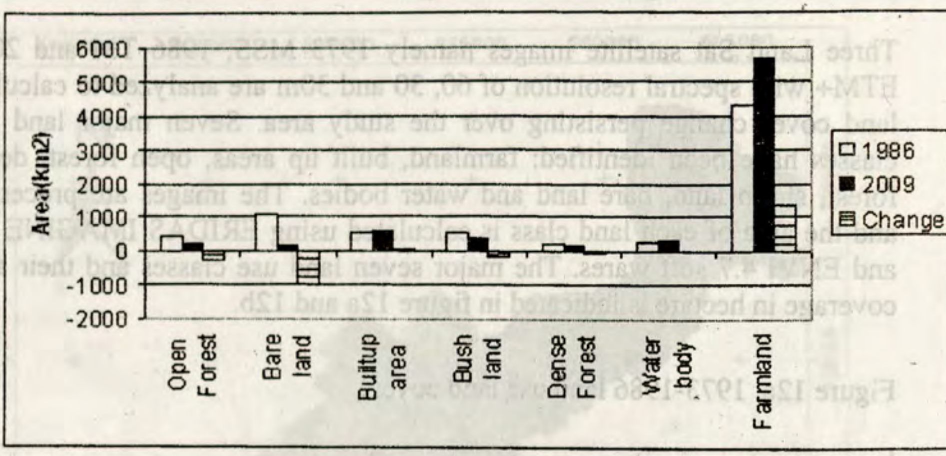
Three Land Sat satellite images namely 1973 MSS, 1986 TM and 2009 ETM+ with spectral resolution of 60, 30 and 30m are analyzed to calculate land cover change persisting over the study area. Seven major land use classes have been identified: farmland, built up areas, open forest, dense forest, shrub land, bare land and water bodies. The images are processed and the area of each land class is calculated using ERIDAS IMAGINE 9.2 and ENVI 4.7 soft wares. The major seven land use classes and their area coverage in hectare is indicated in figure 12a and 12b.

Figure 12a. 1973-1986 land use land cover



Source: Author's own construction based on data acquired from LANDSAT images, 2010

Figure 12b. 1976-2009 land use land cover



Source: Author's own construction based on data acquired from LANDSAT images, 2010

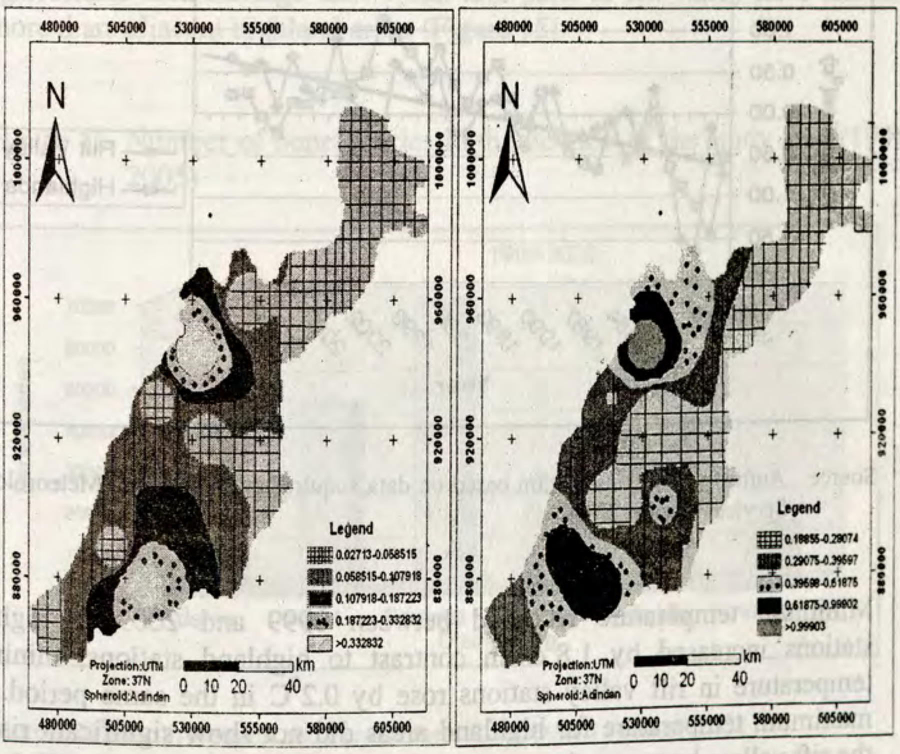
Results and Discussion

Rainfall intensity has not decreased for the past 35 years, both in highland and low land areas even though annual and monthly variations were observed. The total average annual rainfall of highland stations from 1975 to 2009 was 930.2 mm. As compared to researches conducted by UNEP under the Ministry of Agriculture in 1984 (Goebel, 1984), rainfall in highland areas of the study area has shown insignificant rise. Rainfall in the Rift Valley is little less than the current amount. This gives additional evidence that rainfall intensity has not decreased in central Ethiopia for the past 50 years.

Rainfall in highland areas has shown higher annual variance than that of rift valley areas. The highest rainfall variance (with a normalized value greater than 0.187) is registered in highland areas. In the normalized rainfall variance map, higher values indicate higher variance whereas lower values indicate low variance.

The surveys conducted in the study area show that there is a sharp rise in temperature, both in maximum and minimum temperature values. When we observe the changes that occurred in the rift valley area as aggregated from 8 meteorological stations, the rise in temperature is even greater than the one predicted by IPCC. On average, has temperature increased by 0.37^0C in 12 years in the rift valley areas included in this study and by 0.41^0C in highland areas. Figure 13 below shows normalized rainfall and temperature variance.

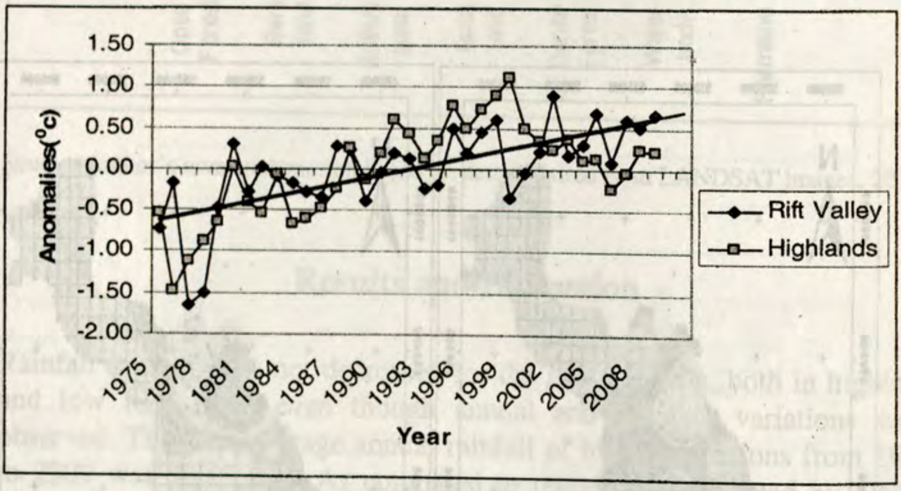
Figure 13. Normalized rainfall (left) and temperature variance (right)



Source: Author's own construction, 2010

The anomaly of temperature in rift valley areas before 1990 an anomaly value was less than zero for many years while the in the preceding years most stations have registered temperature anomalies greater than 0 in ^{0}C. Temperature anomalies have shown tremendous rise after 1990 in a higher rate compared to IPCCS prediction for central Ethiopia, which is 0.9^{0}C to 1.1^{0}C in 2030 as compared to 1961-1990. This means that the temperature is increasing in a faster rate than predicted. Figure 14 shows temperature anomalies for highland and rift valley areas.

Figure 14. Temperature anomalies in rift valley and adjacent highland areas

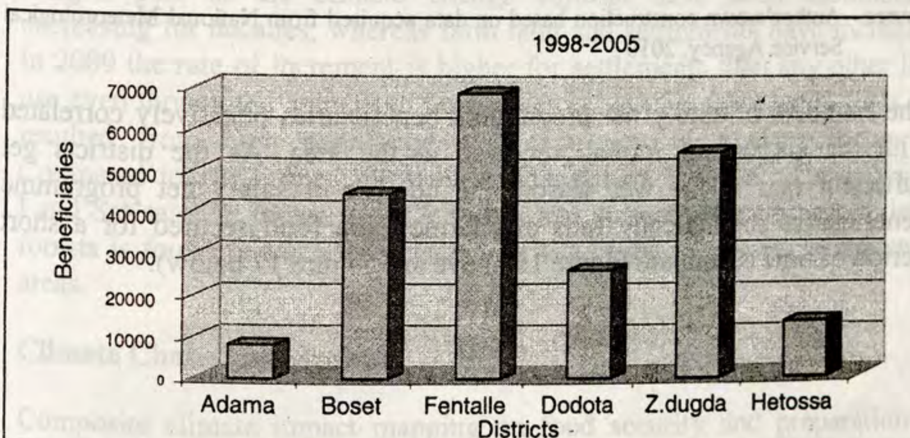


Source: Author's own construction based on data acquired from National Meteorological Service Agency, 2010

Minimum temperature recorded between 1999 and 2009 in highland stations increased by 1.8^{0}c. In contrast to highland stations, minimum temperature in rift valley stations rose by 0.2^{0}C in the same period. The maximum temperature for highland areas did not show significant rise. In the rift valley, however, the amount of maximum temperature is still rising.

There is no clear evidence whether wind speed trend decreased or increased in the study area; in some parts it decreased and in others it did not. Wind speed and climate change have great correlation. The function of wind is higher in drier areas than highland areas as wind is a strong force of erosion in drier parts of the world. Relative humidity is decreasing over time. The rise of temperature is the reason for the mean RH value to fall.Within the study area, districts in semi-arid zone such as Ziway Dugda lost about 40% of cultivated land due to scarcity of rain. In Tiyo District, on the other hand, agricultural land damage is only 1.9% per cultivated land. Highest agricultural damage occurred in 1999 and 2003 when almost half the cultivated land dried due to scarcity of rainfall. The normalized value of agricultural land damage shows that arid parts of rift valley have suffered more than adjacent highland areas (Figure 15).

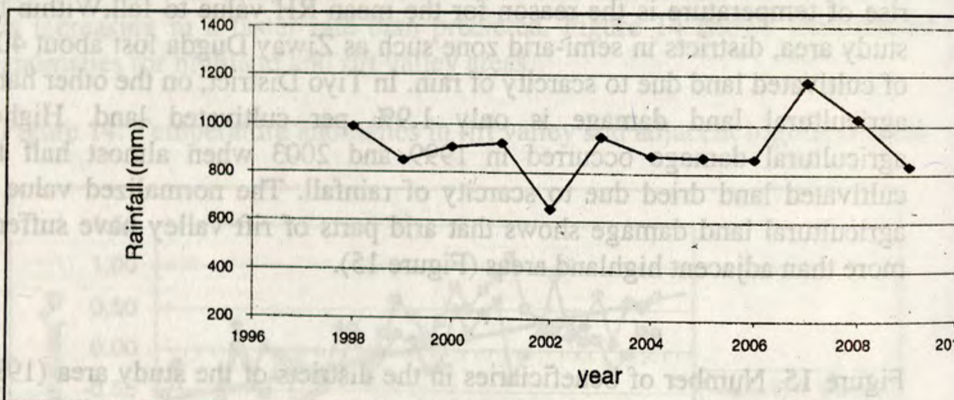
Figure 15. Number of beneficiaries in the districts of the study area (1998-2005)



Source: Disaster Prevention and Preparedness Commission website, 2002

The number of safety net programme beneficiaries started to fall since 2003 as the weather condition improved. This is because the lowest rainfall record was observed in 2002 in between1996 and 2009 with only 653mm average rainfall in the lowland areas (Figure 17). This value is the second highest following the 1984 value when only 576mm average rainfall was registered, resulting in one of the greatest drought in Ethiopia.

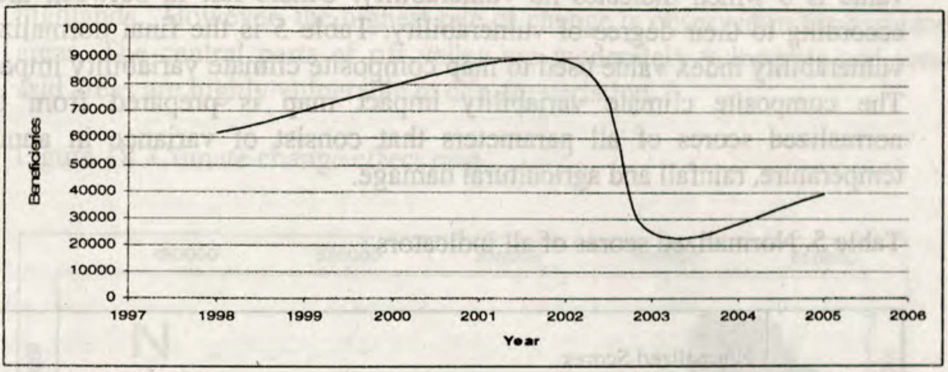
Figure 16. Rainfall distribution



Source: Author's own construction based on data acquired from National Meteorological Service Agency, 2010

The numbers of safety net programme beneficiaries negatively correlated with the amount of rainfall received in the area. As the districts get sufficient rain in the wet season, the number of safety net programme beneficiaries dramatically falls and farmers are food secured for a short period of time (Compare Figure 16 above and Figure 17 below).

Figure 17. Number of beneficiaries of Safety Net



Source: Author's own construction based on Ethiopian DPPC, 2010

The forest ecosystem plays a pivotal role in regulating climate and makes the climatic elements stable in all seasons. However, forests which are the integral part in the climate change concept have been dramatically decreasing for decades; whereas farm land and settlements have increased. In 2009 the rate of increment is higher for settlements than any other land use even though the amount of land cover is high for farm lands. This has resulted from high population and expansion of modern industries. Compared to 1986, open forest has decreased by 888 km^2. The analyzed Land Sat satellite image in 2009 shows that only small coverage of dense forests is found in some pockets and on top of the mountains in the study areas.

Climate Change Impact Map

Composite climate impact mapping on food security and preparation of vulnerability index from the results of aggregated indicators is the final result of this work. All the indicators are normalized and summed together and this helps to get values that fall between 0 and 1. Using the indices, climate variability impact map is prepared. The results are overlaid using IDRISI Andes soft ware and ArcGIS 9.3 overlay analysis tools. No adaptive capacity value is subtracted from the normalized indices since the adaptive capacity is similar in all districts in all indicators. The highest normalized value is 1 and indicates extreme vulnerability and the lowest normalized value is 0 which indicates no vulnerability. Others fall in between them according to their degree of vulnerability. Table 5 is the final normalized vulnerability index value used to map composite climate variability impact. The composite climate variability impact map is prepared from the normalized scores of all parameters that consist of variance in annual temperature, rainfall and agricultural damage.

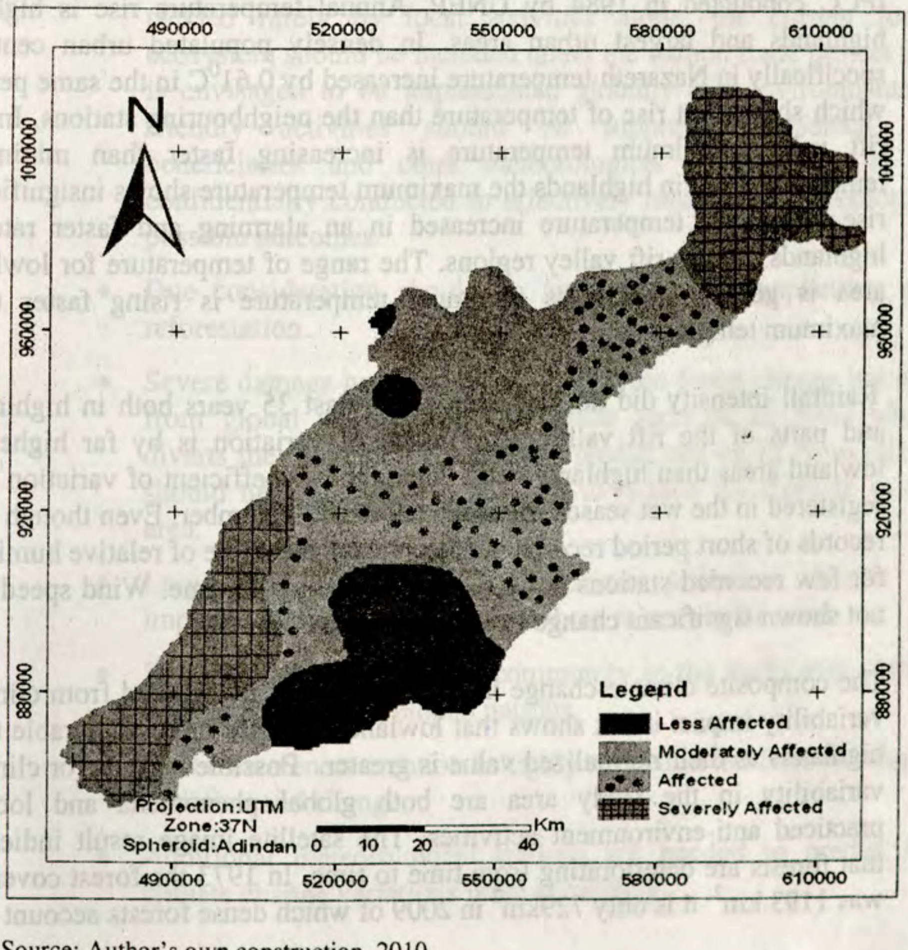
Table 5. Normalized scores of all indicators

	Normalized Scores					
District	Variance in total rainfall	Variance in mean temperature	Agricultural land damage	Sum of the scores	Vulnerability index	Rank
Adama	0.2838	0.4234	0.25	0.9572	0.319067	3
Tiyo	0.0666	0.3262	0	0.3928	0.130933	6
Hetosa	0.0943	0.2331	0.06434	0.39174	0.13058	7
Z. Dugda	0.0965	0.4843	1	1.5808	0.52693	1
Fentalle	0.0468	0.1472	1	1.194	0.398	2
Boset	0.1955	0.3226	0.4	0.9181	0.30603	4
Dodota-Sire	0.0512	0.0154	0.6565	0.7231	0.24103	5

Source: Author's own construction, 2010

The final result indicated that lowland areas are still more vulnerable to multiple stresses that resulted from climate variation than the adjacent highlands. However, the highest rate of change is observed in the highland areas. The central parts of rift valley are moderately vulnerable and semi arid areas are highly vulnerable to climate variation.

Figure 18. Climate change effect map



Source: Author's own construction, 2010

Conclusions and Recommendations

Conclusions

In central Ethiopia where this study is conducted, considerable variability is observed both in highlands and rift valley areas, Temperature increased in the rift valley by 0.37^0C between 1975 and 2009, whereas in highland areas it lifted up by 0.41^0C. This value is greater than the value predicted by IPCC conducted in 1984 by UNEP. Annual temperature rise is high in highlands and largest urban areas. In densely populated urban centers, specifically in Nazareth temperature increased by 0.61^0C in the same period which shows fast rise of temperature than the neighbouring stations. In the rift valley maximum temperature is increasing faster than minimum temperature and in highlands the maximum temperature shows insignificant rise. Minimum temperature increased in an alarming and faster rate in highlands than in rift valley regions. The range of temperature for lowland area is getting smaller as minimum temperature is rising faster than maximum temperature.

Rainfall intensity did not decrease in the past 35 years both in highlands and parts of the rift valley. Coefficient of variation is by far higher in lowland areas than highland areas. The highest coefficient of variation was registered in the wet season, between July and September. Even though few records of short period records had been used, the value of relative humidity for few recorded stations is decreasing from time to time. Wind speed has not shown significant change in the study areas.

The composite climate change impact map which is prepared from climate variability impact index shows that lowland areas are more vulnerable than highlands as their normalized value is greater. Possible reasons for climate variability in the study area are both global phenomena and locally practiced anti-environment activities. The satellite image result indicated that forests are deteriorating from time to time. In 1973 the forest coverage was 1193 $km^{2;}$ it is only 729km^2 in 2009 of which dense forests account for only $241 km^2$. In addition to global condition, the high rate of deforestation that prevailed in the study area has exacerbated the situation.

Recommendations

Based on the findings of the study, the following recommendations have been made:

- Since climate change is a global phenomenon and it could be tackled rarely by local activities alone, the current forest ecosystem should be included under the carbon trade project that is envisaged to be implemented globally and environmentally friendly activities should be supported. Research, on beneficiaries and other meteorological stations, should be confidentially conducted to effectively measure and predict the possible outcomes.
- Due consideration should be given to tree transplanting and reforestation.
- Severe damage has resulted not only from forest change but also from global atmospheric circulation such as El Nino which diverts the direction of wind, and predictions on El Nino effects should be made well in advance to reduce the damage in the area.
- Large and small scale irrigation activities should be implemented in the plain areas where rivers can be used.
- Projects undertaken by the community in the study area should be supported by developed nations.
- Public awareness creation is highly needed in the field of climate variation and change.
- Additional meteorological stations are needed to predict the climate change variations more accurately.

Acknowledgments

I would like to extend my deepest gratitude to Dr. K.V. Suryabhagavan for his continuous guidance and support in the course of writing this paper. I am indebted to the Ethiopian National Meteorological Agency for providing me with useful data. I am equally thankful for the support I got from the Ethiopian Ministry of Water Resource. My thanks equally goes to Arsi Zone DPPC Office and East Shewa and Arsi Zone Health Offices for providing long- term data on malaria outpatients. Last but not least, I wish to acknowledge the support I got from my colleagues.

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ETHIOPIAN JOURNAL OF DEVELOPMENT RESEARCH
COLLEGE OF DEVELOPMENT STUDIES
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