CLIMATE CHANGE IN GILGEL ABBAY CATCHMENT UPPER BLUE NILE, NORTHWESTERN ETHIOPIA

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Abstract

Gilgel Abbay catchment, is one of cereal producing area of Ethiopia, where its productivity is entirely dependent on climatic conditions. This study was aimed at assessing climate change for the last 30 years on this important catchment. Rainfall and temperature data obtained from the catchment stations were used to examine the changes in climate. The mean annual and decadal rainfall and temperature were analyzed to evaluate changes over time. The maximum, minimum and coefficient of variations were also calculated to examine the variability within catchment over time in the catchment. The trend for long time was assessed by linear regression; correlation and significance between the recorded climate data were checked by paired sampled t-test. The results have revealed that over the last 30 years there was both declining and variability of rainfall and rise of temperature in the catchment. There was also spatial and temporal variation of rainfall and temperature in the catchment. Those areas of upper catchment with higher altitude have received more rainfall and lower temperature than the middle and the lower parts. There was also seasonal variation in distribution and amount of rainfall and temperature in the catchment. More rainfall was received during the summer season from June-September in the catchment where as higher temperature was recorded on months of April and May.

Keywords: *climate change; rainfall; temperature; rainfall variability; catchment; trend of change*

Introduction

Climate change is the state of the climate that can be identified by changes in the mean and/or variability of its properties and persists for extended periods, typically decades or longer (IPCC, 2007). While the climate change can occur naturally, population growth, fossil fuel burning, and deforestation has accelerated the increase of greenhouse gasses (carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons) in the atmosphere that trap heat and warm the earth system (USEPA,2004). Recent analyses of climate trends indicate that the global mean surface temperature has increased by about 0.3^0c to 0.68^0c since the late 19^{th} century and by about 0.2^0c to 0.38^0c over the last 40 years (Nicholson and Kim 1997). This trend of increasing surface temperatures could impact the hydrologic cycle and various processes of a watershed system (Band et *al.,* 1996; Chang, 2001; Evans, 2003).

There is emerging evidence that vegetation cover change has a radiative impact on regional climate systems (Lambin and Geist, 2006; Timbal and Arblaster, 2006). This impact is manifested through changes in albedo and evaporation and transpiration processes and partitioning of sensible, latent and ground heat fluxes (Pielke, *et al.*, 2002). Change in precipitation can be manifested through increase in sediment and nutrient loading and reduction in the volume of carrying waters (IPCC, 2007; Chang, 2001). Erosion and sediment transport processes are also influenced by climate change; with the highest soil loss rates occurring in regions that have high variability in precipitation and runoff (Carpenter *et al*., 1992). Global warming also has important consequences on the sustainability of economic sectors such as agriculture, forestry, fisheries, and water supply (USEPA, 2004). The potential influence of climate change is therefore a major concern to watershed management and policy for agrarian country. Changes in the climate regime can influence natural processes of a watershed

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ecosystem (IPCC, 2007; Band *et al.,* 1996; Stone *et al*., 2001) and have long-term implications on economic and ecological processes (USEPA, 2004). The detection of climatic trends, including those predicted to occur from rising concentrations of atmospheric greenhouse gases may be sought in historical climate records.

Ethiopian agriculture is subsistence which depends entirely on rain-fed and highly sensitive to variability of climate over time and space. The climate change can pose significant health and economic threats to the entire nation and its agriculture. The recent drought years of 1965, 1972–73, 1983–84, 1987–88, 1997 and 2006 resulted in low agricultural production and affected millions of rural poor farmers, pastoralists, domestic and wild animals (Hurni,1993; Camberlin,1997; Aredo and Seleshi , 2003; *Amare and Kameswara 2011).* In particular, declining rainfall trends often signify higher probabilities of droughts and have grave ramifications for the environment and social instruments such as drought insurance programmes (Seleshi and Zanke, 2004).

However, there are few studies dealing with climate changes in Ethiopia, in particular in Gilgel Abbay Catchment (GAC). Those who have studied focused on rainfall trends. For instance Osman and Sauerborn (2002) determined that summer rainfall (Kiremt) in the central highlands of Ethiopia declined in the second half of the 20th century. But Seleshi and Zanke (2004) failed to find such a trend over central, northern, and northwestern Ethiopia. Instead, they found a decline of annual and Kiremt rainfall in eastern, southern, and southwestern Ethiopia since 1982. Verdin et *al.* (2005) confirmed that the annual rainfall decline in southwestern and eastern Ethiopia, but argued that while rainfall has been declining in the Northeast since 1996, Kiremt rain has been consistent for the entire nation since the 1960s.

Therefore, there was a need to study the trends and variability in climate elements such as rainfall and temperature in GAC, one of the cereals producing area of Ethiopia. The study analyzed the last 30 years climate change on catchment systems at the regional scale using trend analysis. Accurate information on climate change is essential for appropriate action for agricultural and ecological management. Trend analysis of climate change also provides the baseline data required for proper understanding of changes taking place in catchment with climate and what types of changes are to be expected in the future. Thus, the specific objectives to be realized under this study were determining spatial and temporal variability and trend of climate in GAC. Hence, the study was proposed to adopt "Specific Area" approach as the requirements for different regions vary widely and depend on several factors. Accordingly, one of the most densely populated and cereal producing area of Ethiopia, the GAC area of Lake Tana was proposed for the study.

Methodology

Study Area

Gilgel Abbay Catchment is located at northwestern Ethiopia and stretches between latitudes 10°57`–11°54`N and longitudes 36°38`-37°23`E. In GAC the elevation ranges from 1780m to 3400m. The slope is steep at the southern part of the catchemnt and declines to north wards. GAC comprises Gilgel Abbay River and its tributaries. Gilgel Abbay River contributes more than 40% of the volume of Lake Tana's water and covers about 32% of Lake Tana's total catchment with total area of about 4865km^2. Gilgel Abbay catchment climate falls into two traditional climate zones: 'Woina Dega' (warm 1500-2500m) and 'Dega' (temperate like highland with 2500-3000m). The mean annual rainfall and temperature for the whole catchment was 1553mm and 18^{0}c, respectively. There was spatial and temporal variation of rainfall and temperature in the catchment, because of variation in altitude. The main rainy season which account around 70-90% of the total annual rainfall occur from June to September. According to CSA (2008) there were about 1.2 million people in catchment and about 90% of population live in rural areas and depend on the agriculture**.** The majority of people in the catchment have been practicing mixed farming. Figure1 shows the relative location of the study area, respective of Ethiopia and Lake Tana basin.

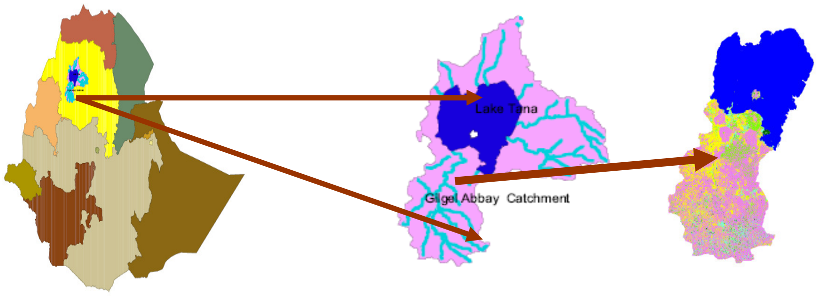

Figure1 Study area map

Data Sources and Methods of Analysis

This study assessed temperature and rainfall data to determine the change and spatial and temporal variability of climate in the catchment. Data used to analyze climate change include rainfall and temperature, obtained from metrological stations. Six major meteorological stations were used as source of climate data representing various biophysical environments of the catchment. These include Sekela, Gundil and Injebar stations from the Southern parts, represent upper part of the catchment, Dangila station, represent the middle part of the catchment areas, and Bahr Dar and Zeghie stations representing the lower catchments of study areas (Table1).

Table1 Gauge stations of Gilgel Abbay Catchment

Stations	Rain fall data	Temperature data	Latitude	Longitude	Year of Data available
Sekela	X	-	11.00	37.22	1988-2007
Gundil	X	X	10.95	37.07	1991-2007
Injibara	X	-	10.97	36.09	1954-2007
Dangila	X	X	11.12	36.83	1954-2008
Zeghie	X	X	11.68	37.32	1974-2007
Bahir Dar	X	X	11.06	37.42	1961-2009

The analysis of climate trends and variability include analysis of the rate of changes in annual, decadal and seasonal rainfall and temperature. It also assessed the analysis of coefficients of variation for the different climatic variables, and probabilities of extreme events both for temperature and rainfall. Wet and dry anomalies and patterns of the events in space and time were also considered in the analysis. The method of moving averages, 10 years span, and the linear regression technique were used for identifying trends of long-term changes.

The linear time series analysis was used to identify the nature of the phenomenon represented by the sequence of observations. Linear regression given by

$(y) = a + bx$ (1)

was fitted to identify time series trend analysis of precipitation and temperature. and slope(b) was calculated by

$b \text{ (slope)} = (N\Sigma XY - (\Sigma X)(\Sigma Y)) / (N\Sigma X^2 - (\Sigma X)^2)$ and (2)

$\text{Intercept } (a) = (\Sigma Y - b(\Sigma X))/N$ 3)

where , x and y are the variables of respective data and time , b is the slope of the regression line , which indicates the status of the fit; that is increasing, decreasing or no change and a is the intercept of the regression line and the y axis and N is number of values or elements.

The paired samples t-test was used to compare the means of two variables and computes the difference between the two variables for each case, and tests to see if the average difference was significantly different from zero. Paired sample t-test is used in 'before after' studies, or when the samples are the matched pairs, or the case is a control study. The test is given by:

$$t = \frac{\bar{d}}{\sqrt{s^2 / n}} \quad (4)$$

Where d bar is the mean difference between two samples, s² is the sample variance, n is the sample size and t is a paired sample t-test with n-1 degrees of freedom.

Results and Discussion

Trends of Rainfall in GAC

The mean annual rainfall for the whole catchment was 1553 mm; mean minimum rainfall was 1249 mm whereas the mean maximum rainfall was 2273mm (Table2). This shows that the rainfall amount within the catchment was adequate although the coefficient of variation was high (17%). The coefficient of change which was about 16.2 indicated that presence of positive rainfall in the catchment. This means for the last 30 and more years, there was more variability of rainfall on those years.

However, there was spatial variation on the mean rainfall amount annually within the catchment. The annual mean, maximum and minimum rainfall was the highest for upper stations as compared to middle and lower parts of the catchment. The mean annual rainfall for Gundil, Injibar and Sekela was 2348, 2181 and 1796mm, respectively (Table2). The coefficient of variation was also the lowest for these stations and was positive. These means the upper part of the catchment was getting higher rainfall than the middle and the lower parts. The coefficient of variation was low for those stations with higher rainfall than the lower rainfall except Sekela. This implies that, the annual variability was related to the amount of rainfall, the stations were receiving.

The relationship between the time and rainfall in Injibara and Gundil was 0.424 and 0.448, respectively. Except Sekela and Dangila, all were significant at ($p<0.005$).There was variation in rainfall within the catchment because of difference in altitude. In general, there was highest amount of rainfall within the catchment but it declines from south to northwards.

Table 2 annual mean rain fall in Gilgel Abbay Catchment

Stations	Mean	CV%	Max	Min	Slope	Correlation Coefficient	P Value
Sekela	1795.7	19.21	2383.7(2006)	1187.0	22.3	0.274	0.071
Gundil	2348.3	11.43	2721.1(2005)	1798(1995)	26.4	0.448	0.004
Injibara	2181.1	12.89	2828.9(1999)	1612(1959)	13.1	0.424	0.000
Dangila	1556.3	14.37	1960.2(1999)	1180.2(1968)	6.9	0.118	0.347
Zeghie	1499.7	16.52	1896.7(1999)	823.6(1991)	10.1	0.261	0.005
Bahir Dar	1435.6	14.12	1844.7(1973)	894.6(1992)	2.6	0.337	0.003
Catchment's Total	1552.8	16.89	2272.6	1249.2	16.2	0.379	0.000

Seasonal Distribution and Variation of Rainfall

The movement of ITCZ influences rainfall in Ethiopia in general and GAC in particular. The summer months account for a large proportion of mean annual rainfall (90 per cent) occurs between June and September. There were the same pattern but different magnitude of rainfall within the stations, for instance Injibar, which is located at upper part of the catchment has high amount of rainfall as high as 500mm per month for about 10 months in a year, Dangila at the middle of the catchment, has received 350mm per month and Bahir Dar at the lower course of the river received about 300mm (Figure.2). Thus, the main rainy season for catchment was summer. But there was variation both in a number of months and the amount of rainfall within the catchment. At the upper part of the catchment the amount of rainfall and the rainy months are longer as compared to the middle and the lower part of the catchment.

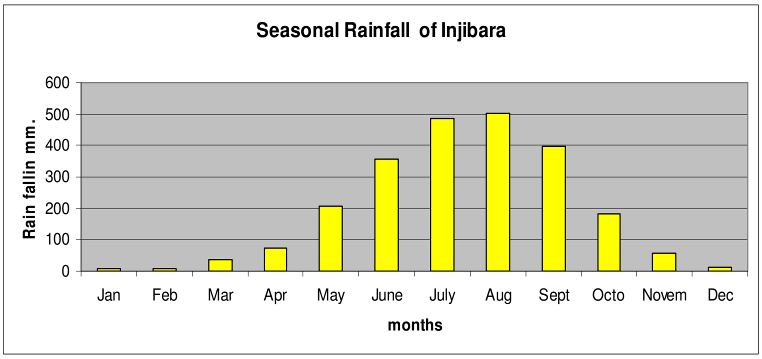

Figure 2 Monthly mean rainfall of GAC Stations

Decadal Trend of Rainfall

The analysis was done from 1978 to 2007 by breaking the time into three decadal periods that is (1978-1987, 1988-1997 and 1998-2007). The mean annual rainfall was increasing from 1978-1987 to 1988- 1997, from 1628.9mm to 1771.2 mm. But it declined from 1771.2 mm to 1666.3mm from 1988-1997 to 1998-2007 (Table3). This shows that the mean rainfall within the stated decades was varying from time to time. However, the coefficient of variability has increased from 6.21% to 9.5% and then to 10.12% on respective decades. Thus, within the decades it was possible to say that there was more variability of rainfall.

However, by considering the coefficient of change there was declining trend of rainfall within the stated period. In the first decade (1978-1987) it was 3.3, and has declined to -11.8 and to -12.1 within the remaining decades respectively (Table3). The correlation values were 0.206, -0.507 and 0.041 respectively. This shows that the relationship between rainfall amount and decades have weak but positive value for the first decade, negative relatively better relationship for the second decade and very weak positive relation for the last decade. The amount of rainfall was significant at ($p<0.05$). Thus, it is possible to say that rainfall within the decadal periods in GAC has shown declining rate.

Table 3 decadal trends of rainfall in GAC

Parameters	Decadal periods		
	1978-1987	1988-1997	1998-2007
Mean	1628.9	1771.2	1666.3
CV%	6.21	9.5	10.12
Max	1792.9(1987)	1973.6(1989)	2089.3(2006)
Min	1471.1(1980)	1443.3(1995)	1646.2(2007)
Slope	3.2557	-11.769	-12.143
Correlation Coefficient	0.206	-0.507	0.041
P Value	0.000	0.000	0.001

Trends of Temperature in GAC

The value of the regression line indicated the presence of long term trend of temperature data and some of the stations (Dangila and Zeghie) have trend lines with values 0.0052^0c and 0.0028^0c per year. Other stations (Gundil and Bahir Dar) have relatively higher trends (0.0735^0c and 0.0403^0c) per year. Gundil has the largest single increase in average annual temperature with trend of $+0.0735^0$c per year (Table4). The average annual increase in temperature for the entire GAC, was $+0.03045^0$c per year. Correlation was positive in Gundil (0.657^0c), others have positive but lowest correlation. It was significance only in Gundil and Bahir Dar ($p<0.05$) but others were not. The mean temperature was lower in Gundil and variability was lowest for this station. Overall catchment temperature was explained by 30.5% variations (Table4). This implies mean temperature was comparatively low and less variable in upper part of catchment than other parts. The higher temperature was recorded on the lower part of the catchment than the upper parts. The mean, maximum and minimum temperature was higher for lower parts and declined upwards in the catchment. This shows temperature declines from upper part to the lower part on opposite direction to that of rainfall. This analysis was opposite of the analysis of rain fall patterns within the catchment that is rainfall decrease from south part of the catchment to north wards but temperature goes on opposite direction. It was also coinciding with the general principle which says temperature decrease with altitude increase whereas rainfall increases with altitude if other things have no influence on topography.

Table 4 mean annual and coefficient variation of temperature GAC stations

Stations	Mean	CV%	Max	Min	Slope	Correlation coefficient	P value
Gundil	15.8	2.53	16.6	15.1	0.0735	0.657	0.000
Dangila	16.9	5.33	19.8	15	0.0052	0.077	0.581
Zeghie	19.2	3.56	20.1	17.5	0.0028	0.242	0.070
Bahir Dar	19.2	5.21	20.8	17.0	0.0403	0.476	0.000
Catchment's Total	17.8	16.85	19.3	16.2	0.03045	0.336	0.070

Seasonal Distribution and Variation of Temperature

In all stations the temperature was highest from March to May and the lowest was recorded in all stations from June to September and other months have intermediate temperature. But there was difference in magnitude of temperature within the stations in the catchment. Because of high altitude at the upper part of the catchment there was lower temperature as compared to middle and lower parts of the catchment (Figure.3).

Decadal Trend of Temperature

Thirty years temperature record was considered to analyze the decadal change in trends of temperature in the catchment. The annual mean temperature has declined by -0.2mm per year from the first to the second decades. But it has increased by 0.8 mm per year from the second decade to the last decade (Table5). Thus, based on this descriptive information, it was possible to say that there was variability of temperature within the stated decade in GAC. But slope has indicated that the temperature from 1977-1988 was negative and low. From this decade on wards it has started to increase, from 1989-1998 it was 0.0343 and increased to 0.1382 from 1999-2008. There was 0.1039^{0}c per decade increase within these decades (Table5). This shows increment of temperature in the catchment within the last 20 years. The correlation was significant except the first decade. This implies that there was both variability and declining of temperature in the catchment on the last 30 years.

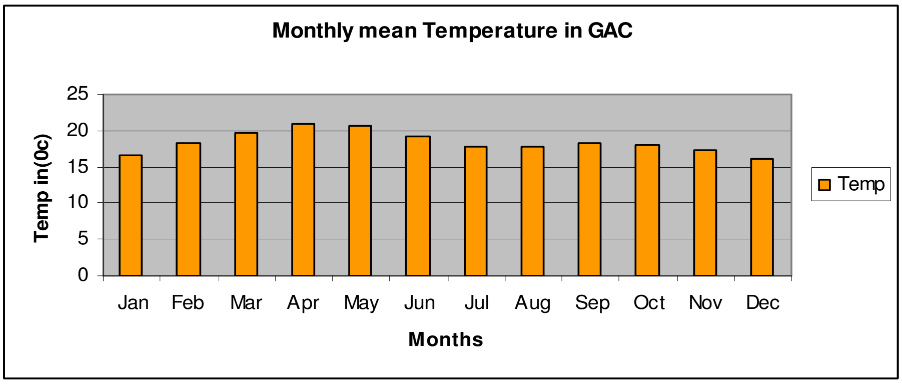

Figure 3 monthly mean temperature of GAC Stations

Table 5 decadal mean annual and variance of temperature GAC stations

Parameters	Decadal periods		
	1977-1988	1989-1998	1999-2008
Mean	16.7	16.5	17.3
CV%	4.2	3.0	4.0
Max	17.3	17.3	17.9
Min	15	15.7	15.8
Slope	-0.0178	0.0343	0.1382
Correlation coefficient	0.476	0.046	0.296
P value	0.000	0.864	0.283

Conclusion

There was both spatial and temporal variation of rainfall and temperature. The upper part of the catchment has received more rainfall than the middle and lower parts. However, the processes which lead to temperature rise and rainfall decline and variability are related to natural and man induced factors. Those which affect global climate may have effect on local climate. The climate variability in study area is associated with ENSO, but the recent declining of rainfall and increase of temperature was related to local factors such as land cover and use changes. Thus, in GAC for the last 30 years there was declining and variability of rainfall and rise of temperature.

Climate change has a variety of implications for the GAC because climate change alters grasslands, forests, fisheries, and other resources and their values. Changes in air temperature and rainfall resulted increases in frequency and intensity of drought and flood events have long-term implications for the viability of the ecosystems. As climatic patterns change, so also do the spatial distribution of agro ecological zones, habitats, distribution patterns of plant diseases and pests, fish population and ocean circulation patterns which can have significant impacts on agriculture and food production. Planned adaptation measures which are multisectoral in nature, aimed at altering the adaptive capacity of the agricultural system or facilitating specific adaptations are needed in case of GAC. The adjustment options are either short or long term adaptation such as seasonal changes and sowing dates; different variety or species; water supply and irrigation system; new crop varieties and promotion of agro-forestry, adaptive management with suitable species.

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