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DETECTION OF CLIMATE TRENDS OVER ETHIOPIA USING GEOSPATIAL TECHNIQUES

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Abstract: Ethiopia is expected to be hardest hit by climate change; to which agriculture is the most vulnerable. Point analysis of climate data for one of the semi arid areas (Mekelle, Northern Ethiopia) for the period of 1980-2010 showed that minimum temperature for the months of October through January had an increasing trend while maximum temperature for the hot season (April- June) and annual rainfall had no significant trend and were inconsistent. Raster climate data including maximum temperature for warm season (April- June), cold season (October- January) and rainfall for the rainy season (June- September) for the years 1946 and 2006 were extracted from Climate Research Unit (CRU) Geospatial Raster Data Portal for Ethiopia. The change detection is unidirectional trend analysis between two time periods of 1946 and 2006. Temperature shows increasing trend but rainfall shows fluctuation. Region- Specific detailed and seasonal climate studies are needed and to be integrated with local context of agriculture, livelihoods, forecasts and development plans for effective Early Warning Systems to utilize climate potentials and minimize natural disasters. This study serves as a milestone for further detailed agroclimatic and sector based analysis of spatio temporal climate change patterns, impact assessment and adaptation and mitigation strategies.

Keywords: Ethiopia; climate change detection; CRU; GIS; Spatiotemporal analysis.

INTRODUCTION

Ethiopia is expected to be hardest hit by climate change; and the most vulnerable sectors are agriculture, water resources and human health. It is predicted that climate change could lead to increased water stress, overall reduction in agricultural productivity and yields, and expansion of vector habitats (spatial ecology) of diseases such as malaria. Climate change can significantly reverse the progress towards poverty reduction and food security in Ethiopia. Over the last five decades frequency of occurrence of extreme weather events such as drought and flood show an increasing trend. Particularly since the 1980s, droughts of varied intensity have occurred every 4 or 5 years and seem to be more frequent since 1997. Seasonal and inter-annual rainfall variability has increased and temperature shows an increasing trend. Analyzing and assessing the spatio-temporal climate variability trends would help better understand impacts of climate change to formulate better strategies for climate change adaptation and mitigation in Ethiopia and encourage local proactive community participation and national efforts as a contribution to global climate change mitigation (FAO, 2006, 2007, 2008, 2010; NMSA, 2008; James, 2004).

The climate of a location is affected by its latitude, terrain, and altitude, as well as nearby water bodies and their currents and inherent to climate are changes, both long-term and short-term. Short-term climate changes represent periodic or intermittent changes that occur which is climate variability (IPCC, 2007; Wing, et al., 2008; Abbadi and Nitin, 2010 and 2011).

Recent climate trends based on UNDP climate data indicate change parameters in temperature and rainfall. There is a clear and observable positive trend in temperature. Ethiopia shows a broadly consistent warming trend, with observations of increasing minimum and maximum temperatures over the past fifty years (McSweemy, et al., 2010). The NAPA reported average annual minimum temperatures rising by 0.2 – 0.4°C per decade and average annual maximum temperature by 0.1°C per decade (FDRE, 2008; GEF, 2006). Other studies report broadly similar rates. There are also reports of increasing trends in the frequency of hot days, increasing trends in the frequency of hot nights, and decreases in the frequency of cold days and nights. Strong increases have been experienced over the entire country, with slightly greater increases in the Nile valley. Further temperature increases are anticipated over the next decade and beyond as climate change accelerates. The trends are less clear for precipitation, and no clear trend has been observed at the national level over the past sixty years. However, some trends start to emerge when specific regions and seasons are considered. The NAPA reported a declining trend of annual rainfall in northern and South-Western Ethiopia. Other studies suggest a decline in rainfall in the South-West and South-East, but little change in central areas. Climate change contributes significantly to poverty and food insecurity. Proactive approaches to managing climate risks within vulnerable rural communities and among institutions operating at community, sub-national, and national levels is a crucial step toward achieving the sustainable economic development (NMA, 2008; Temesgen, et al., 2008;). This study deals with application of geospatial techniques for climate change detection in Ethiopia for the period of 1946 to 2006 and case study of point data analysis of semi-arid environment of Ethiopia (Mekelle station) for the period of 1980 to 2010 to detect and describe spatio tempotal trends and changes occurred during the study period

METHODOLOGY

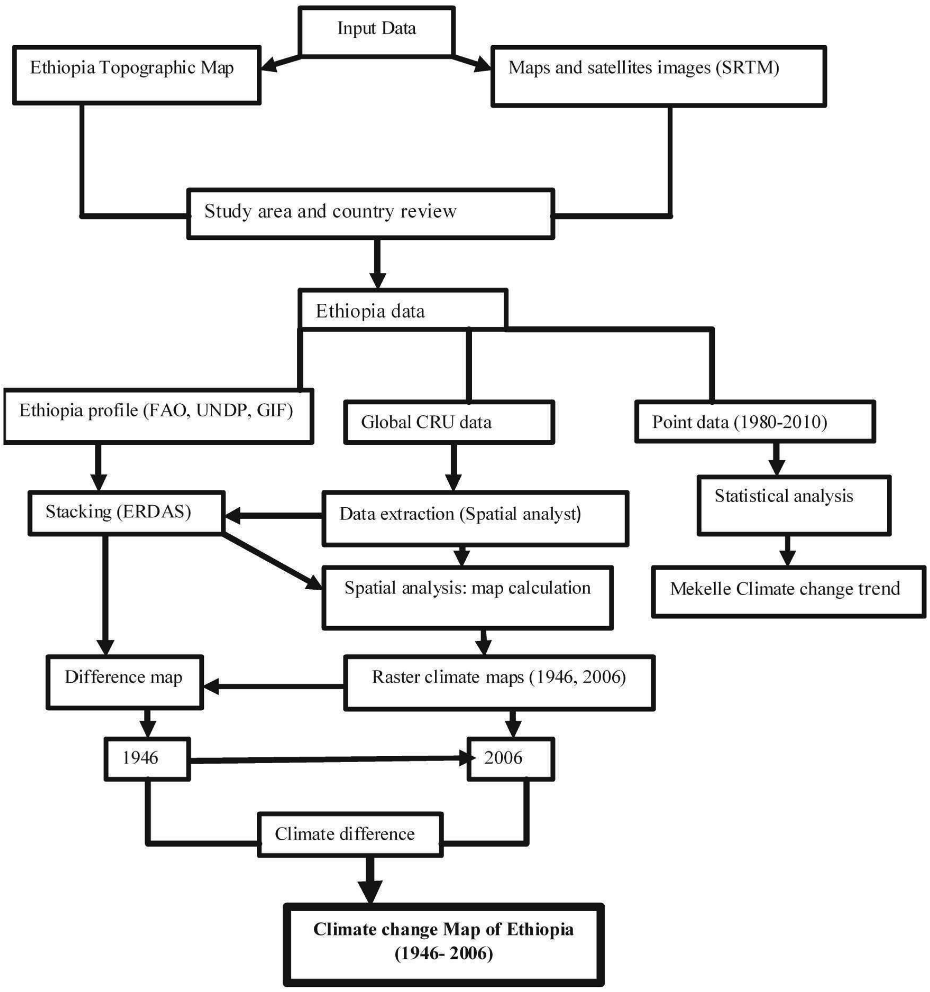

Figure1: Conceptual flow chart of climate trend detection and analysis in Ethiopia

STUDY AREA

This study focuses on spatio temporal climate change detection at country scale and point analysis of Mekelle station.

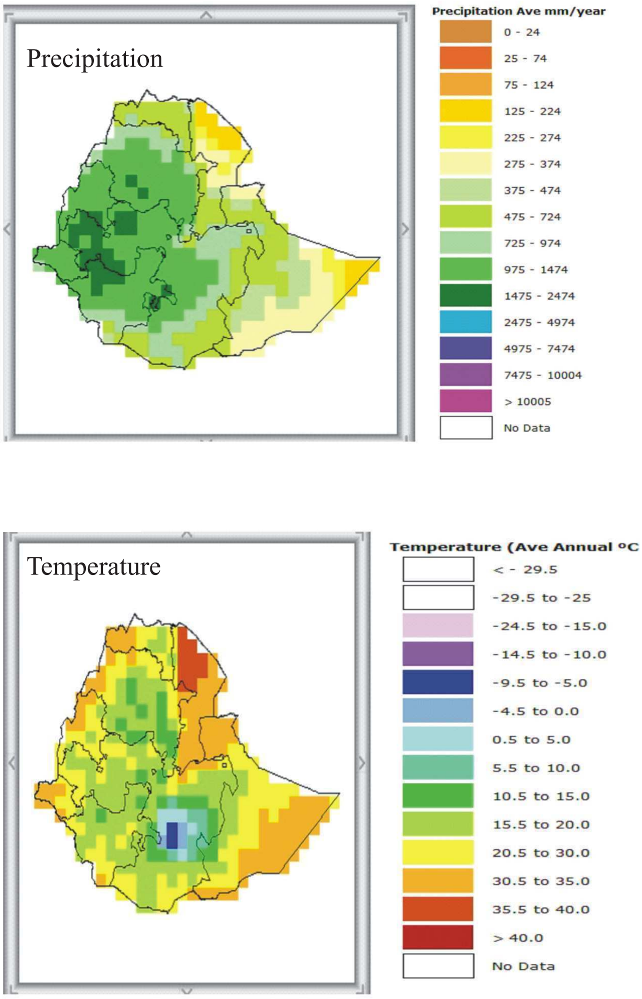

Figure2. Climate map of Ethiopia
Source: FAO Country Profiles and Mapping Information System , Ethiopia

Data acquisition

a) Data (1980-2010) from semi arid Ethiopia (Mekelle station)

The data set included maximum temperature for the hot season (April- June), minimum temperature for the cold season (October- January) and annual rainfall for the period of 1980-2010.

b) Climate Research Unit (CRU) dataset

Raster climate data including maximum temperature for warm season (April- June), cold season (October- January) and rainfall for the rainy season (June- September) for the years 1946 and and 2006 were extracted from CRU Geospatial Raster Data Portal for Ethiopia to detect climate change in 60 years time period. 60 years period was assumed to be reasonable time span to detect climate change based on data availability to the Ethiopian context. The CGIAR Consortium for Spatial Information (CGIAR- CSI) provides an-easy-to-use CRU TS 2.1 Global Climate Data for the entire world. The data has been produced by the CRU of University of East Anglia (UEA), and reformatted by International Water Management Institute (IWMI) to provide for easy access and to use in geospatial analysis using common GIS software. The CRU TS 2.1 Global Climate Dataset is comprised of 1224 monthly time-series of climate variables, for the period 1901-2002, covering the global land surface, excluding Antarctica, at 0.5 degrees resolution. The nine climate variables available through this dataset are: daily mean, minimum and maximum temperature, diurnal temperature range, precipitation, wet day frequency, frost day frequency, vapor pressure and cloud cover. The CRU is a component of the University of East Anglia, UK, and is one of the leading institutions concerned with the study of natural and anthropogenic climate change.

Data processing and analysis

a) Geospatial operations

Stacking, Spatial Analysis, Map calculation, overlaying and change detection were executed in ENVI 4.7 and ARC GIS 10 to generate spatiotemporal climate change difference maps for the indicated 60 years. The procedure of data extraction and stacking and analysis included:

Extraction (ARCGIS 10): Extraction through spatial masking to clip global data to Ethiopia;
Stacking**:** Stacking monthly data of a single parameter for the years 1946 and 2006 for further manipulation and analysis; and
Spatial Analysis, map calculation, union and difference mapping: Raster calculator, map algebra /map calculation and difference map for climate variability.

Climate variation (1946-2006): Difference map (GIS overlaying and subtraction techniques) was calculated as: *Raster calculator (Subtraction): [2006] - [1946]*
Ethiopian Climate Raster Data Extraction from CRU for the years 1946 and 2006 included the following parameters.

b) Statistical analysis

Descriptive statistics:
It was applied to summarize data with measure of central tendency and measure of variability or dispersion (standard deviation and variance), the minimum and maximum variables. Descriptive summary was prepared for each parameter. Coefficient of variation (C.V.) was reported as a percentage value for each parameter. The variability of climate variables over the study period was examined by calculating coefficient of variation (CV).

Time series trend analysis (Parametric and Non- Parametric Tests):
The trend of time series of climate variable is the rate at which it changes over a time period. The trend may be linear or non-linear. The task of trend analysis is to characterize and account for other sources of variation and to identify and quantify the actual trend in a statistically rigorous way. Statistical significance is computed via a univariate non-parametric Mann-Kendall test. Moreover, detection of statistically significant changes through time is done by regressing climate variables (dependent) on time (independent. Different researchers have applied Mann Kendall (non parametric) and parametric regression tests for temporal trend analysis. The Mann-Kendall test is a non-parametric test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values. One benefit of this test is that the data need not conform to any particular distribution. This test is the result of the development of the nonparametric trend test first proposed by Mann-Kendall (1945) and has advantage of nonparametric robustness against departures from normality (Gilbert, 1987, Kendall, 1975). We applied both trend analysis methods to explore temporal trend of climate and production variables. Trends occur in two ways: a gradual change over time that is consistent in direction (monotonic) or an abrupt shift at a specific point in time (step trend). Linear trends are monotonic trends. Non Parametric time series Mann Kendall trend test is adopted for testing temporal trend of climate variables as recommended by WMO (WMO, 1996; WMO, 2009; IPCC, 1994).
In parametric (linear trends) tests, temporal trend of climate variable is a function of time and it is regressed over time span and expressed as:

$$Y = \hat{a}_0 + \hat{a}_1 X$$

Where, $\hat{a}_0$ is a constant (regression *intercept*), $\hat{a}_1$ is the slope (the regression coefficient, $\hat{a}_{1=}$ y_2-y_1/x_2-x_1), X is the value of the independent variable (time), and Y is the value of the dependent variable (trend of climate variable).
Non-parametric test is represented by Null hypothesis and alternative hypotheses as follows:
Null hypothesis:
Ho: f (t) is constant (i.e. not dependent on time), where, *t* is time
Ho: $\hat{a} = 0$ (data not linearly dependent on time)
Alternate hypothesis:
HA: f (t) is not constant
HA: $\hat{a} \neq 0$
We followed monotonic trend test in our study with both parametric and non parametric trend (Mann Kendall) tests. Statistical trend analysis is a hypothesis testing process. The null hypothesis (Ho) is that there is no significant trend; each test has its own parameters for accepting or rejecting Ho. Failure to reject Ho does not prove that there is not a trend, but indicates that the evidence is not sufficient to conclude with a specified level of confidence that a trend exists. The alternate hypothesis (Ha) is that there is significant trend. XLSTAT 12 (excel add ons) both parametric and non-parametric time series tests were applied for temporal trend of variables. Seasonal decomposition can also be applied in XLSTAT2012. The change per unit time in a time series having a linear trend is estimated by applying a simple non-parametric procedure of Sen's estimator of slope.
Softwares used: ARC GIS 10, Excel and SPSS.

RESULTS AND DISCUSSION

Parameter values as compared to pixel values: Temperature and rainfall of pixel value is calculated by dividing each pixel value by 10 and the actual values of parameters are the figures indicated in each map divided by 10 (e.g. the value of rainfall appearing in the map is 12750 the actual rainfall would be 1275mm and the same applies for temperature. Temperature of 183 in the map legend would mean the actual temperature is 18.3^{0}c).

Spatiotemporal climate Change, Ethiopia (1946- 2006)

Rainfall

1946 monthly rainfall (June-September) shows that August received the highest rainfall (580mm), July (448mm) followed by September (398mm) and June(369mm). 2006 monthly rainfall shows August received 366mm, July 441mm, September (255mm) and June (294mm). There was a clear shift of monthly intensity of rainfall from 1946 to 2006. In 1946 the pick rainy month was August but in 2006 it was shifted to July. Likewise, in 1946 June received the least amount of rainfall but in 2006 it increased in amount and replaced September where September received the least rainfall amount in 2006. Seasonal rainfall (June to September) was generated through raster calculator (addition) of monthly rainfall June through September for both 1946 and 2006. Rainfall change during 1946 to 2006 was calculated as the difference between 1946 and 2006 seasonal rainfall and it is simply directional trend between the two time periods as shown in figure 3. Rainfall generally show declining trend from periods 1946 to 2006. Moist areas of western and south Western Ethiopia are showing fall of rain fall showing their forest covers have been deteriorating through time. Interestingly, the drier areas show some positive trends owing to massive environmental rehabilitation and restoration of degraded lands into productive lands in the last 25 years.

Most of Ethiopia experiences one main wet season (called 'Kiremt') from mid-June to mid-September (up to 350mm per month in the wettest regions), when the ITCZ is at its northern-most position. Parts of northern and central Ethiopia also have a secondary wet season of sporadic, and considerably lesser, rainfall from February to May (called the 'Belg'). The southern regions of Ethiopia experience two distinct wet seasons which occur as the ITCZ passes through this more southern position The March to May 'Belg' season is the main rainfall season yielding 100-200mm per month, followed by a lesser rainfall season in October to December called 'Bega' (around 100mm per month). The eastern most corner of Ethiopia receives very little rainfall at any time of year. The movements of the ITCZ are sensitive to variations in Indian Ocean sea-surface temperatures and vary from year to year, hence the onset and duration of the rainfall seasons vary considerably inter-annually, causing frequent drought. The most well documented cause of this variability is the El Niño Southern Oscillation (ENSO). Warm phases of ENSO (El Niño) have been associated with reduced rainfall in the main wet season, JAS, in north and central Ethiopia causing severe drought and famine, but also with enhanced rainfalls in the earlier February to April rainfall season which mainly affects southern Ethiopia.

Studies by UNDP and NASA show similar results of rainfall fluctuation in Ethiopia. The strong inter-annual and inter-decadal variability in Ethiopia's rainfall makes it difficult to detect long-term trends. There is not a statistically significant trend in observed mean rainfall in any season in Ethiopia between 1960 and 2006. Decreases in JAS rainfall observed in the 1980s have shown recovery in the 1990s and 2000s (UNDP Portal). Study by NASA (NASA, 2012), has identified a link between a warming Indian Ocean and less rainfall in eastern and southern Africa. Computer models and observations show a decline in rainfall, with implications for the region's food security. Rainfall in eastern Africa during the rainy season, which runs from March through May, has declined about 15 percent since the 1980s, according to records from ground stations and satellites. Statistical analyses show that this decline is due to irregularities in the transport of moisture between the ocean and land, brought about by rising Indian Ocean temperatures.

Maximum temperature variation (April- June, 1946- 2006)

Figure5. Maximum temperature April 1946 and 2006 Maximum temperature for the months April through June for both 1946 and 2006 was computed with same procedure for rainfall and changes in monthly maximum temperature are detected for each month. Maximum temperature of April increased by 2.3^{0}c during the period of 1946 to 2006 (Figure 4).

Minimum temperature variation (October- January, 1946-2006)

Minimum temperature shows two extreme facts. In some areas it is falling down than before indicating that they are becoming cooler than before. In other areas, minimum temperature is rising up that places that were very cold are decreasing their coldness. These data are in support of Ethiopian Meteorological Agency records. These data are evidence of global climate change for the existence of extreme weather changes justifying that some areas unusually are becoming cold and some becoming warmer and hotter than before because of global warming.

Over the last five decades frequency of occurrence of extreme weather events such as drought and flood show an increasing trend. Particularly since the 1980s, droughts of various intensity have occurred every 4 or 5 years and seem to be more frequent since 1997. Seasonal and inter-annual rainfall variability has increased and temperature shows an increasing trend. The spatial and temporal distribution of the available water resources is however highly uneven as driven by the variable climate (NMSA, 2008). Mean annual temperature has increased by 1.3°C between 1960 and 2006, an average rate of 0.28°C per decade (Figure 5). The increase in temperature in Ethiopia has been most rapid in JAS at a rate of 0.32°C per decade. Daily temperature observations show significantly increasing trends in the frequency of hot days, and much large increasing trends in the frequency of hot nights (UNDP country portal).

Case study: Temporal climate variation of point data (Mekelle station, 1980-2010)

Temporal climate trend

Table1. Temporal trend of climate variables at Mekelle (1980-2010)

Variable	R^2	Standard error	F	P-value	Trend
Maximum temperature (^{0}c)					
April	0.003	0.07	0.102	0.75	NS (No significant trend)
May	0.052	0.02	1.2	0.29	NS (No significant trend)
June	0.0005	0.025	0.029	0.87	NS (No significant trend)
Minimum temperature (^{0}c)					
October	0.26	0.021	9.6	0.005	Significant trend
November	0.21	0.029	7.1	0.014	Significant trend
December	0.21	0.036	6.5	0.018	Significant trend
January	0.22	0.03	6.4	0.019	Significant trend
Annual rainfall (mm)	0.154	2.1	4.2	0.052	NS (No significant trend)

Minimum temperature (October –January) showed significant trend while maximum temperature and rainfall had no significant trend during 1980-2010 period based on XLSTAT 2012 parametric and non- parametric trend tests (Figure 6).

Table2. Descriptive statistics of climate variables at Mekelle station (1980-2010)

Statistics	Maximum temperature (^{0}c)			Minimum temperature ((^{0}c)				Annual
	April	May	June	Oct	Nov	Dec	Jan	rainfall (mm)
Mean	27.74	29.07	29.41	10.93	9.58	8.21	8.48	482
Max	29.40	30.10	31.50	13.60	13.60	11.90	11.60	710
Min	25.90	26.70	26.90	9.20	7.30	4.40	5.20	230
S.D	0.87	0.99	1.19	1.15	1.50	1.87	1.56	116
C.V	0.03	0.03	0.04	0.11	0.16	0.23	0.18	0.24
C.V (%)	3.00	3.00	4.00	11.00	16.00	23.00	18.00	24

Minimum temperature (October –January) was highly variable with coefficient of variation ranging 11% to 23 % whereas maximum temperature was stable with minimum variation during the period of 1980 to 2010 (table2). Minimum temperature (October –January) showed significant increasing trend while maximum temperature and rainfall had no significant trend during 1980-2010 period (table1, figure 6). Minimum temperature of October had the highest increasing rate of 0.026^{0}c\annuum (figure9). This increasing trend of minimum shows that seasons are getting hotter in recent years. This is also in line with global climate change and variability trends that some places are getting hotter in which cold periods of the year are getting hotter. This variability is manifested either by rise of maximum temperatures or increment of minimum temperatures so that years and seasons become hotter than their past climatic condition. Rainfall was characterized by High inter-annual variability. June 1981 was the warmest month with highest maximum temperature of 31.5^{0}c while December 1981 was the coldest month with minimum temperature of 4.4^{0}c indicating that the year 1981 had the warmest month in June and the coldest month in December. This year had highest record of maximum temperature and lowest record of minimum temperature. Years 1980, 2001 and 2006 were relatively wet years while year 1984 was the driest year manifested by the worst 1984 drought in Northern Ethiopia Comparative results of Mekelle area have also been obtained from World Weather information Service (WWIS). Maximum temperature for the warm season of April to June shows some increasing and decreasing trend for the month of April in some areas. There is increasing trend in May but very distinct increment in June which is in agreement with other studies (FAO, UNDP and IPCC). Minimum temperature of the cold season (October- January) is rising up.

Resilience against climate change in Ethiopia

Whilst land degradation has already taken and continues to take the leverage, climate change poses another real challenge to the realization of the full potential of Ethiopian agriculture. Ethiopia is expected to be hardest hit by climate change; and the most vulnerable sectors are agriculture, water resources and human health. It is predicted that climate change could lead to increased water stress, overall reduction in agricultural productivity and expansion of spatial ecology of vectors of diseases such as malaria to highlands of Ethiopia. Health GIS studies of malaria have also shown this trend. An option for adaptation to climate change and necessary condition for sustainable agriculture in itself is sustainable land management (SLM) and rehabilitation of degraded lands. Community Based Integrated Watershed Management (CBIWSM) approach was adopted as one of the top climate change adaptation strategies in Ethiopia. Massive sustainable local community based natural resource management efforts have been undertaken to reverse this situation and there are a lot of success stories in the last 20 years which includes: Water harvesting, Irrigation (crop diversification and intensification), Zero grazing , A (re)forestation , plantation, agroforestry, closure areas, protected forests, intensive and integrated watershed management approach/ SWC and conservation agriculture. Land degradation is primed to exacerbate climate change impacts. Conversely, SLM practices constitute key adaptation measures by resulting in reduced soil erosion, improved water retention, and improved land productivity. Sustainable Land Management (SLM) requires addressing of the underlying causes to land degradation. Environmental rehabilitation efforts in Ethiopia have brought about reclamation of waste lands, re-vegetation of degraded hillsides, restoration of damaged pasturelands, and adoption of improved soil and water conservation and management technologies in cultivated lands. SLM practices and climate change adaptation and mitigation strategies are mutually supportive and represent win-win options (WoldeAmlak Bewuket, 2009).

CONCLUSION

The Ethiopian climate has shown a drastic spatiotemporal climate change in the last 60 years (1946-2006) which manifest the impact of global warming at local level. Our findings were in line with global trends of temperature and rainfall changing patterns. CRU is one of the huge climate resource data center with its raster global climate data portal for the period of 1901 to 2006. GIS has efficient tools to extract, manipulate and analyse global data in to area of interest and generate spatial data within short time. It can help us analyses spatiotemporal climate change. There was an increasing trend of both maximum and minimum temperature while there was no consistency in rainfall patterns.

Detailed agroclimate based analysis is required to generate high spatial resolution outputs with locally specific application for climate change assessment and design effective adaptation strategies in the face of climate change. Synergy is needed to complement local climatological knowledge and build capacity of community for early Warning System at local level to better utilize (exploit) climatological potentials and minimize risks due to natural disasters. It is believed that the results of this study will serve as a milestone for further detailed analysis and impact assessment studies.

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