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Assessment of Climate Change Impacts on Highland Lake of Eastern Ethiopia

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Abstract — Lakes are fragile and vulnerable to global and local climate changes, and human intervention. Changes in lake ecosystems as a result of climatic and anthropogenic factors can in turn have significant impact on the livelihood of a society. Ethiopia is one of the countries that have experienced significant reduction in volume and surface area of its lakes. Recently some lakes are drying due to microclimate changes and over exploitation of water. One of the lakes that have recently dried is Lake Alemaya. The objective of this research was, therefore, to assess the micro-climate change and impacts on Lake Alemaya. Working toward this, data collection was done through analysis of meteorological data, field observation, interview and questionnaires. The study showed that different changes occurred in the area of Lake Alemaya that contributed to the lake disappearance. The average yearly minimum temperature increased by 0.7°c (8%) from 1980 to 2008 though the mean maximum temperature varied only little 0.4°c (2%). The general trend of annual rainfall in the area increased by 10% between the years 1980 to 2008. The mean monthly rainfall revealed that there is also a seasonal shift during years 1980-1992 as compared to 1997 to 2008: dry season got 10% more rainfall; wet season got 5% and longer. The study found that microclimatic factors have contributed for gradual deterioration and the final vanish of the Lake Alemaya.

Key words — Climate change, Lake Ecosystems, Temperature, Rainfall, Alemaya

1 INTRODUCTION

Climate is changing at an unprecedented rate [8]. Most of this change can be attributed to the anthropogenic emissions of greenhouse gases and unfavorable land use changes [8; 15].The annual mass of greenhouse gases released to the atmosphere has increased over the last decades. Owing to the increasing mass of greenhouse gases, the capacity of the atmosphere to trap heat has increased at an alarming rate. Depending on the future scenario, global temperatures may increase by 1.1 to 6.4 °c toward 2100 [8] making impacts more threatening. The projected changes in temperature will affect the delicate climatic balance of the Earth planet. Likely climatic changes include droughts, floods, heat waves and extreme precipitation [8].

Lake ecosystems are one of the natural ecosystems that are highly prone to the impact of global climate change (most importantly increased annual mean temperature and frequent drought) and human intervention; [7; 8]. Increased annual mean temperature leads to increased annual water loss through surface evapotranspiration. This is especially true for shallow lakes with large surface area to volume ratio. Moreover, increased human intervention in the form of uncontrolled water withdrawal for irrigation and domestic uses and uncontrolled agricultural activities can lead to lake system degradation and complete disappearance in the worst case [7; 10]. This is especially true for hydrologically closed lakes (lakes with no inflowing rivers). Thus, climate change and uncontrolled human interventions may lead to loss of a lake system along with all its ecosystem services. The consequences to human life and other life forms can be serious [1; 12].

Ethiopia has received daunting impacts from sever degradation of natural resource such as creeping of desertification, drying of rivers, lowering of ground water level and shrinking of lakes [11; 14]. Ethiopia is one of the countries in which large numbers of lakes that make up the east African great rift-valley lake system are found. In addition to the rift-valley lakes there are a number of large and small lakes across the country. Some of the Ethiopian rift-valley lakes have experienced drastic reduction in volume and surface coverage due to climate change and uncontrolled human intervention [17]. The problem is not limited to the rift-valley lakes: Lake Alemaya is the best evidence of lake disappearance in Ethiopia [16].

The Main Objective of this research is to assess the changing climatic condition and its impact on Lake Alemaya. For this reason, studying about the contribution of climate change and other factors to the gradual reduction and final disappearance of the lake has become increasingly important. The analysis will provide important mitigation mechanism to protect other similar lake's in the region. In addition, analysis of the impact on the local community from the loss of the lake's ecosystem services will have a significant implication to find ways of adaptation under the current environmental set up.

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2 Methodology

2.1 Description of the study area

Lake Alemaya (Locally known as Haramaya) is located in the Eastern part of Ethiopia in Haramaya district, delimited earlier by a longitude and latitude of respectively 90 22′ 03′′– 90 27′ 12′′N and 410 58′ 14′′–420 05′ 26′′ E with a catchment area of about 50Km2. The climate is sub-humid with an average annual rainfall of about 800 mm with more than 100mm per month for wet seasons. The lake received inflows from small streams that drain catchments to the west and north of the lake and floods from small hills in adjacent watersheds [2].

The area surrounding of the lake has undergone significant change in land use and land cover over the last half century that eventually resulted in its complete loss [5]. During the 1960s, the area is used to be covered with thick vegetation, predominantly bushes and climbers [2]. Now a day the area is almost completely used for agricultural production, primarily plantation of khat, maize, sorghum and vegetables. Water has always been abstracted primary to grow Khat, previously directly from the lake and later from underground. Erosion from the lake's catchment principally caused by intense rainfall, steep topography, and poor vegetation cover coupled with cultivation of steep lands has also significantly affected the lake by reducing its storage capacity [13].

2.2 Data collection methods

Data collection methods involve among others review of previous studies on Lake Alemaya, time series records of meteorological data (air temperature and rainfall). Review of previous studies is primarily focused at gathering information about relevant temporal change in the different aspects of the lake (e.g. gradual reduction in the lake's surface area) and changes in the lakes catchment (such as change in land use and land cover and shift in vegetation composition) that have directly to do with the devolution of the lake.

Meteorological data (average minimum and maximum monthly air temperature and rainfall) was collected from the Ethiopian Meteorological Agency. The meteorological data spans over the years (1980 to 2008). The data for the Alemaya meteorological station was considered because this station is very near by the lake and measurements here can more accurately represent measurements that would be made over the lake. Air temperature and rainfall were considered because these are the primary microclimatic factors that can have direct impact on a lake and its ecosystems. Data on air temperature and rainfall were collected at a monthly temporal resolution, so that long term annual change and long term seasonal shift can be probed in detail.

2.3 Data analysis methods

The meteorological data: rainfall and air temperature, were organized on yearly and monthly bases. The data were then presented graphically so that yearly and seasonal trends in these rainfall and air temperature can be depicted clearly. In depth qualitative analysis were conducted on the bases of these data in an attempt to investigate the interrelationship between these climatic variables in the area and their association with gradual change in the lake's system. Basic descriptive statistics using SPSS was also used to study the long term average values of the climatic variables and their variability about the long term averages.

3 Results and Discussion

3.1 Results

Temperature: annual

Recent years show a shift in mean annual minimum temperature towards relatively higher (long term average of 10 over the years 1997-2008) and consistent (standard deviation of 0.945) value as compared to the long term average for the years 1980-1992 (9.3 with standard deviation of 1.419). The mean annual maximum temperature has also exhibited an increment but to lesser extent as compared to the mean annual minimum temperature. Table1 and 2 present summary of information about the mean annual minimum and maximum temperature over the study period.

Table 1. Descriptive Statistics (mean annual minimum temp in ^{0}C)

	N	Minimum	Maximum	Mean	Std. Deviation
1980-2008	25	6.2	11.2	9.6	1.23600
1980-1992	13	6.2	11.2	9.3	1.41850
1997-2008	12	7.4	11	10	.94497

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TABLE 2. DESCRIPTIVE STATISTICS (MEAN ANNUAL MAXIMUM TEMP IN ^{0}C)

	N	Minimum	Maximum	Mean	Std. Deviation
1980-2008	25	23	24.4	23.9	.40976
1980-1992	13	23	24.4	23.7	.41324
1997-2008	12	23.6	24.4	24.1	.26400

Closer look at temperature records shows that higher fluctuation is observed for the annual mean minimum temperature. For example, lower values – as compared to the long term average annual minimum temperature of 7.55, 6.23, 7.46 and 7.36oc were recorded for the years 1984, 1985, 1986 and 1998. On the other hand higher values – as compared to the long term average annual minimum temperature – above 10.5oc were recorded for different years. It is noticed that most of lower average annual minimum temperature records were seen (figure 1) during the first set of years (1980-1992), while higher values of annual average minimum temperature values were recorded over the years 1997-2008. The same pattern is observed for the annual average maximum temperatures, but the level of shift is less significant. For instance, if we take 24oc as a threshold, most values over the years 1980-1992 are lower than the threshold value while the reverse is true for the years 1997-2008

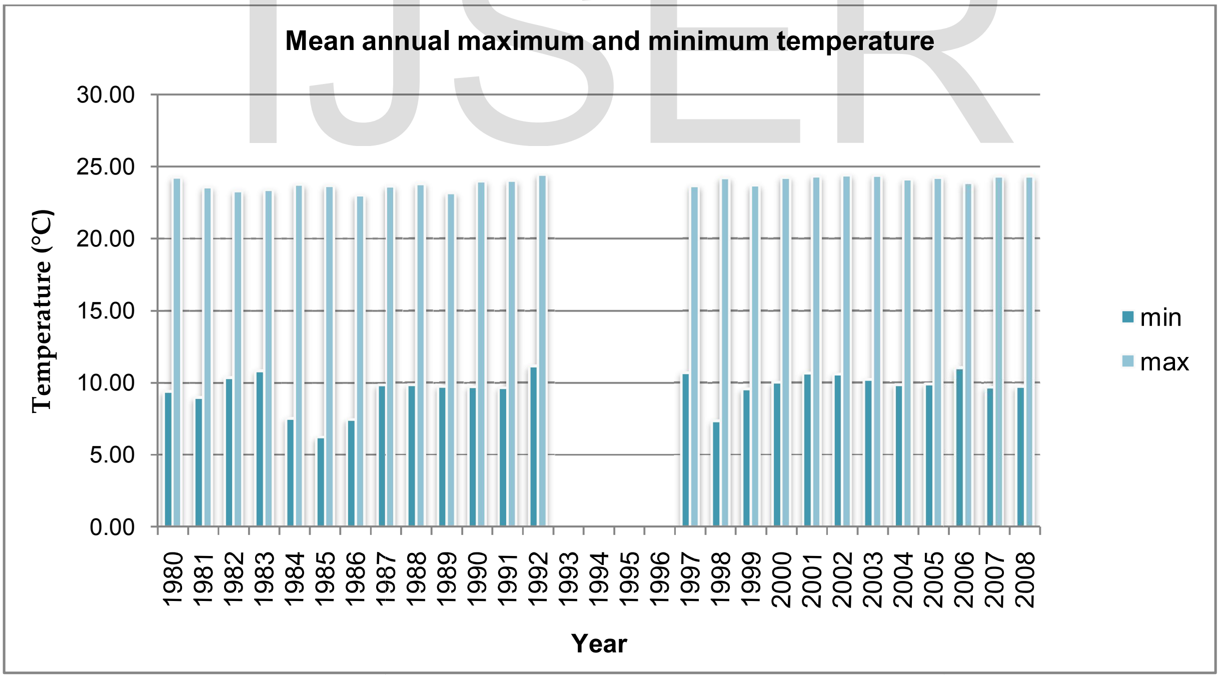

Fig.1 Trend in mean annual minimum and maximum temperature

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Seasonal

Seasonality in temperature is significant for the minimum temperature than the maximum temperature. Mean monthly minimum temperature exhibited variation over a range of approximately 3oc to 14oc, while monthly average maximum temperature varied over a smaller range of approximately 22oc to 26oc. Higher monthly average minimum temperature above 10oc were observed for the months March to September, while lower values (3oc to 8oc) were observed for the remaining months. On the other hand, monthly average maximum temperature was above 24oc for the months February to March.

It is apparent (figure 2 and 3) that there is no significant shift in temperature seasonality over years, but the average minimum and maximum temperatures have increased for almost all months in recent years. The rise in the average monthly minimum temperature is especially significant for the months September to January. For the years 1980-1992 there used to be an abrupt rise in average monthly minimum temperature from about 4oc in January to about 8oc February. But over the years 1992-2008 the average monthly minimum temperature stays at about 6oc as it goes from January to February, resulting in the only month (February) for which the average minimum temperature decreased over recent years as compared to previous years. For the months March and April the average minimum temperature stayed the same.

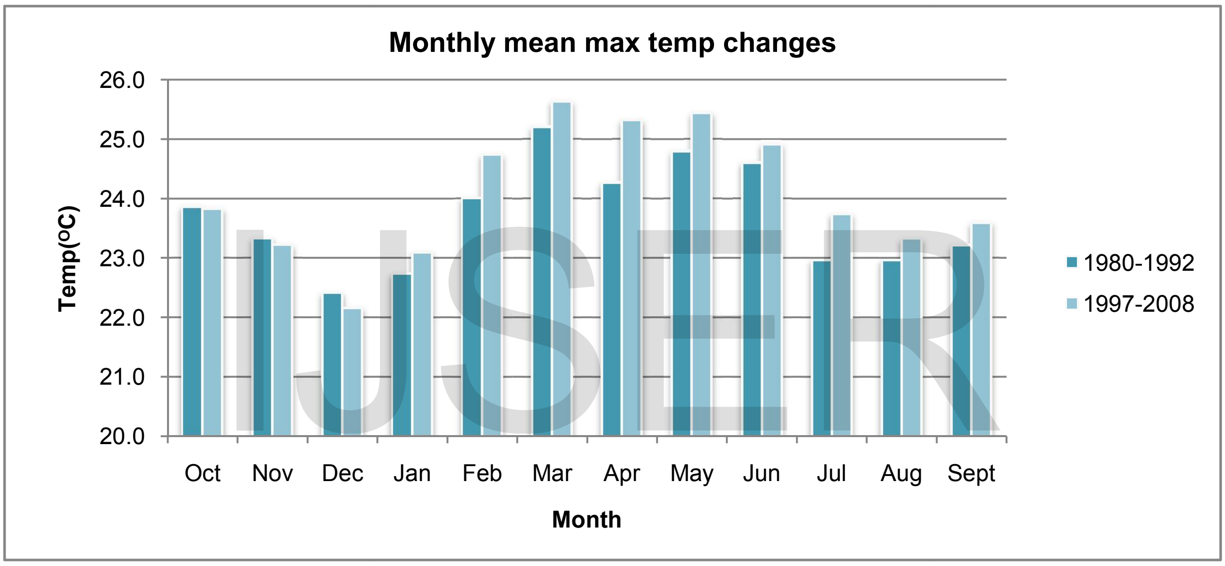

Fig. 2 Monthly patterns in mean minimum temperature

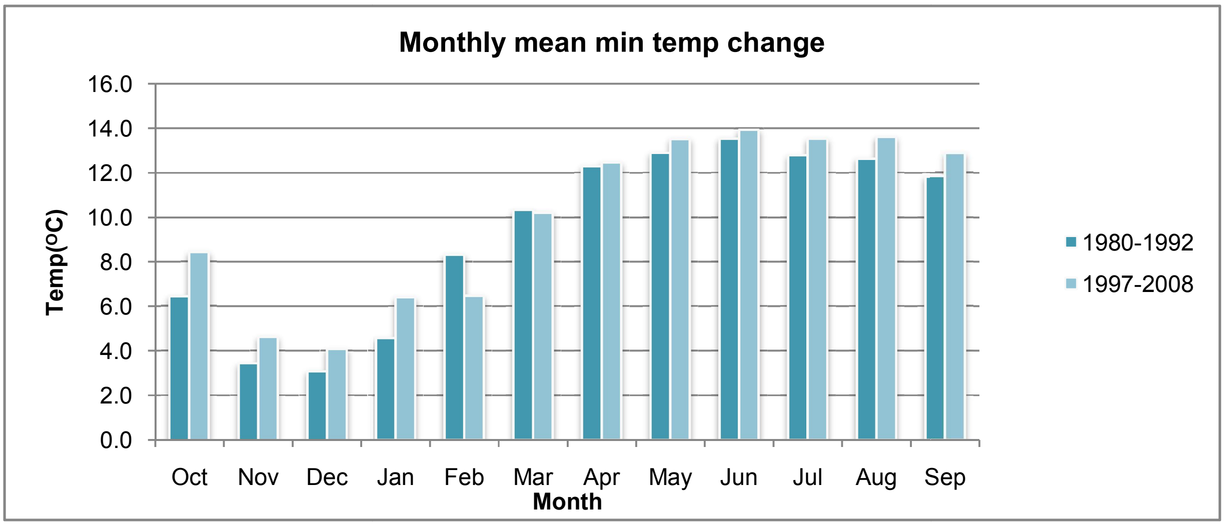

Fig. 3 Monthly patterns in mean maximum temperature

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Evaporation

Evaporation is an essential part of water cycle where water is naturally lost from water bodies or soil. Free water evaporation occurs from the lake basin based on the climatic condition in the area [16]. From the study conducted by Tamiru et al [16] evaporation rate of water from the lake Alemaya was calculated. Thus, the annual average rate of evaporation from the lake was 1269mm.It was noticed that free evaporation from the lake surface can be a factor for the water loss [16]. Annual potential and actual evapotranspiration were also calculated, 715 and 641 mm respectively. As one can naturally expect, the actual and potential evapotranspiration in the lake area attains higher values over the months for which higher daily temperature is recorded.

TABLE 3. MONTHLY EVAPOTRANSPIRATION FROM LAKE ALEMAYA BASIN IN MILLIMETERS

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
P	11.7	19.5	65.8	102.8	94	45.4	98.8	149.3	103.7	37.6	12.2	10	751
PET	43	51.7	63.3	70.3	74.4	77.6	68.3	67.9	65.3	51.3	44.4	37.5	715
AET	20.9	25.5	63.3	70.3	74.4	68.8	68.3	67.9	65.3	54.3	38.6	23.3	641

Source: Tamiru et al 2006

Rainfall: annual

Time series data on the rainfall measured at the Alemaya meteorological station over the years 1980 to 2008 exhibits fluctuation between a minimum value of 467mm/year and maximum value of 1104mm/year. Despite the significant inter-annual variation in the total rainfall, as can be seen from the standard deviation in table 4, the general trend in annual rainfall seems to be virtually constant, especially over the years 1997-2008 (figure 4), with a long term total annual rainfall of 808mm.

TABLE 4. DESCRIPTIVE STATICS (TOTAL ANNUAL RAINFALL IN MM)

	N	Minimum	Maximum	Mean	Std. Deviation
1980-2008	25	467.00	1104.00	808.6	155.21
1980-1992	13	467.00	1044.00	771.8	167.86
1997-2008	12	607.00	1104.00	848.5	135.95

Relative to the long term average (808mm/year), higher total annual rainfall values of 1044, 947, 992, 965 and 1104 mm were recorded respectively for years 1981, 1987, 1997, 2001, 2006. On the other hand, lower total annual rainfall values of 596, 547, 467, 634 and 607mm were recorded for the years 1980, 1984, 1985, 1992, and 2002 respectively. Rainfall exhibits generally direct and inverse relationship with average annual minimum temperature and average annual maximum temperature respectively (figure 4) with apparently different sensitivity level to variation in these variables. The mean annual rainfall increased for the years (1997-2008) as compared to the previous years (1980-1992) and the change is 77 mm.

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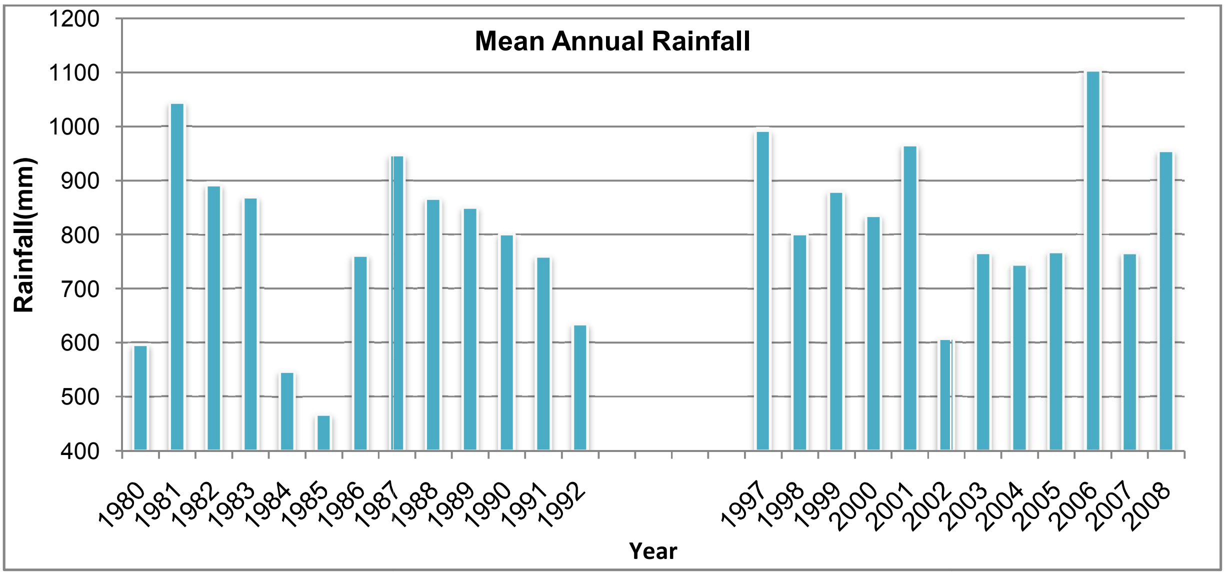

Fig. 4 Time series values of total annual rainfall

Seasonal

Long term monthly average rainfall clearly shows that the lake's region has two rainy seasons which spans over the months March-May and July-September with a peak value above 150mm/month.

Closer look at the monthly rainfall patter shows slight shift in the rainy season. For example, comparison of mean monthly rainfall over the years 1980-1992 and 1997-2008 as presented in (figure 5) shows shift of the beginning of the first rainy season from March to April and the end of the second rainy season from October to November. For the years 1997-2008 the beginning of the first rainy season coincides with the month for which the mean monthly rainfall reaches the peak (i.e., April), while the end of first rainy season stays at the same time it was for the years 1980-1992 (i.e., June). This results in net shortening of the first rainy season in the later years. Moreover, the total rainfall volume for the first rainy season has decreased in the later years. The fact that the mean monthly rainfall for the months October and November increased for the later years shows not only slight shift of the end of the second rainy season but also increased in the total rainfall volume for this season. However, the total annual rainfall is fairly constant across the years for which data is available.

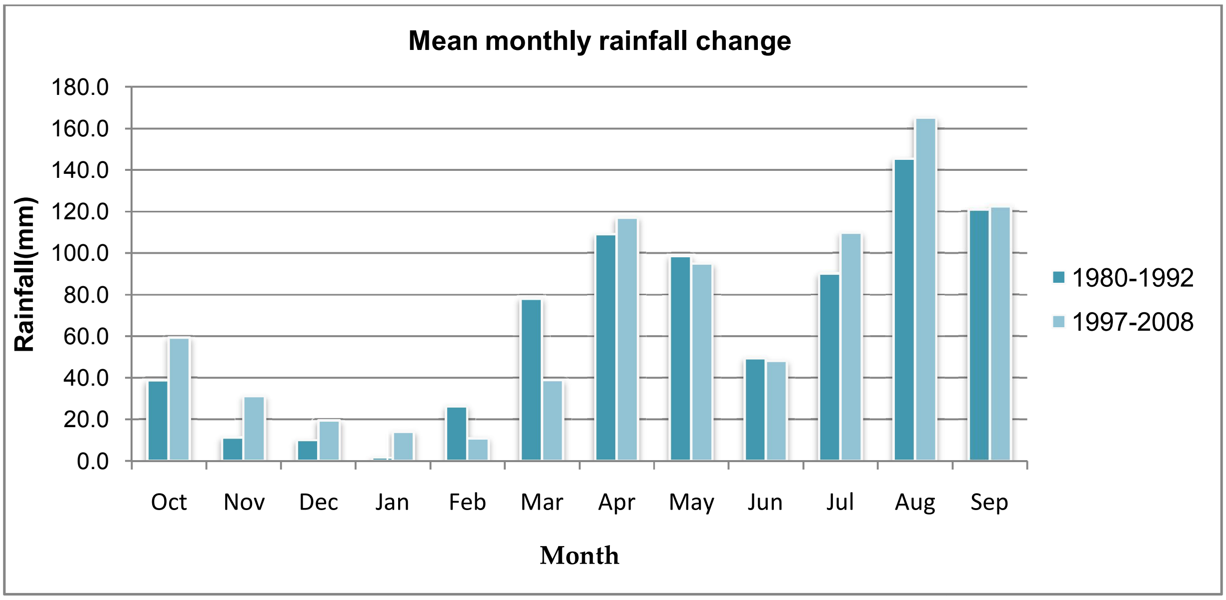

Fig. 5 Comparison of monthly pattern in mean rainfall volume (1980-1992 and 1997-2008)

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Lake surface area reduction

The time at which the surface area and depth of the Lake Alemaya started to diminish cannot be precisely indicated. However, review of previous literature and interview with the local community suggests that the lake started to decrease around the end of 1980s. Brook [3] indicated that the surface area of the lake during the year 1986-1987 was about 4.72Km2 while an independent study by Meklit [11] using remote sensing methods shows that the surface area of the lake in 1996 is only about 2.7 Km2. Sparse data on the surface area measurements of the lake in the subsequent years depicts rapid decrease in the lake's surface area and the lake virtually disappeared around year 2005. Response of questionnaire distributed to the local community also showed that the lake started decreasing in volume around 1993 and completely disappeared in 2005. Thus, it is apparent that the devolution of Lake Alemaya is a relatively recent phenomenon.

Perception of local community about the climate change

Based on questionnaire and interview conducted, out of the total respondents, 87 % have observed change in seasonality of air temperature and few respondents have no perception about the changes. The respondents further expressed that they noticed elongated and warmer sunny season over years in the area. Based on questionnaire conducted, 91% of the respondents perceived change in the seasonality of rainfall. They stated that there is a shift in seasonality of rainfall in the current time. Thus, 90% of the respondents indicated that the rainy season is getting shorter and 79% of the respondents noticed less rainfall in the current years. When the perception of local community compared to the meteorological data obtained from national meteorology for Alemaya district, there is some similarity in the result of monthly rainfall in the area. Both revealed that there is a seasonal shift in rainfall. However, local community perceived shorter rainy seasons. As to the perception of the local community, the seasonal shift in rainfall has also resulted in drought and flooding.

Human intervention

Human activities in the area of Lake Alemaya believed to be the major causes for vanishing of the lake. Human activities in the surrounding of Lake Alemaya had a potential to affect lake ecosystems. Based on questionnaire, interview and focus group discussion conducted, the most important factors related to human intervention the resulted in the vanished of Lake Alemaya are deforestation, expansion of agriculture and water abstraction. Deforestation started earnestly in 1980's with intensive agricultural activities. High population number has intensified the demand of water. As a result, continuous water abstraction from Lake Alemaya was observed over years. Even in the current time, ground water is withdrawn without any control by the surrounding community. Water from the ground and surface of the lake has been excessively pumped by the local farmers to irrigate their vegetables and crops. In the current years, area around the lake has been totally converted to agriculture.

3.2. Discussion

Uncertainties in the result

The time scale for meteorological data used for this study was 25 years which span over 1980 to 2008. But, 5 years data were not found between the years 1992 to 1997 probably because of civil war in the country. Thus, meteorological data were not reported to the national metrological station during this time. As a result, generalization of trends in climatic variables to the whole year between 1980 and 2008 may not be appropriate and the missed data in between the years might have influenced the annual trends in temperature and rainfall patterns. However, the calculated maximum and minimum average temperature and average annual rainfall showed similarity with previous studies on the lake.

Currently, the lake has dried out completely and it is difficult to notice all of the ecosystem services it used to provide during field observation. This hindered to compare of results obtained through different methods with field observation. However, all the results obtained by different methods were further cross-checked and analyzed

Comparison with other studies

The study found that there are lesser changes in mean maximum annual temperature than mean minimum annual temperature and annual mean rainfall for the year 1980-2008. The mean annual rainfall of the recent years (1997-2008) increased by 10% as compared to the previous years (1980-1992) while the mean maximum annual temperature has increased only by 2%. A study conducted by Brook [3] indicated a steady rise of air temperature. Moreover, study conducted by Meklit [11] showed increased mean maximum and minimum temperature.

On the other hand, both study by Brook and Meklit do not go with the observed rainfall trend as identified in this study. While Brook [3] mentioned insignificant change in the rainfall in the area and Meklit [11] mentioned even decreasing rainfall trend, this study shows increasing trend in rainfall. These discrepancies may be attributed to the fact that there is high mismatch on the time span included in each study. The two studies considered time span between 1960 and 2002 while this study considered relatively recent years (1980- 2008). Thus, it is evident that very recently the trend in annual rainfall has increased.

Meteorological data Vs local perception

The analysis of meteorological data revealed that there are changes in climatic patterns in the area of Lake Alemaya. However, the local community perception from results of questionnaire, interview and focus group discussion revealed that there are significant changes in climatic conditions: smaller rainfall, rise air temperature and hotter weather condition.

With regard to seasonal shift and climate variables, both the local community perception and result from meteorological data seem to go hand in hand. However, there is strong difference on the magnitude of seasonality shift as perceived by the local community and as derived from meteorological

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data. While there is a strong witness for significant shift in seasonality of rainfall among the local community, analysis of meteorological data shows only a slight shift in the seasonality of rainfall. The local community further blames on seasonal shift of rainfall for affecting crop production, and harvesting. Similar differences also exist between the local perception and result of meteorological data about the length of rainfall and dry seasons. The local community perceive that the length of rainy season has significantly decreased. But analysis of meteorological data shows prolonged rainy season.

Other meteorological factors such as wind and humidity may determine the perceived level of rainfall. For example, if the wind speed is very high and humidity is very low the rain water may evaporate in a short period. Hence, the local community may perceive that there is less rainfall than the actual. Such factors might have resulted in the differences between the local perception and result of meteorological data. In addition, the local community perception is based more on the daily weather condition. However, the study focused on only monthly and annual patterns both in temperature and rainfall in the area. These factors might also lead to variation in the result. A study conducted by Chattopadhyay and Hulme [4] and Jones [9]also confirmed all climatic variables like humidity, wind, temperature etc. are an important component of climate where any of these changes are important factor in analyzing the potential evapotranspiration.

4 Conclusions

The result of the investigation of relevant meteorological and other data collected through interview, questionnaire and focus group discussion showed that the gradual shrinking of the lake that ultimately led to its disappearance is primarily attributed to anthropogenic factors and climatic change in the area. Unprecedented change in land use and land cover has prevailed over the area of Lake Alemaya during the last 25 years. Progressive and continues land use and land cover change has been reported by the interviewees of this study and by previous researches most importantly by Meklit [11]. Important changes include intensive deforestation followed by expansion of irrigation based agriculture and increased people settlement adjacent to the lake area. The primary crop that has taken over the previous forest area around Lake Alemaya is Khat, crops and vegetation.

In addition to change in land use and land cover in the area, water has been over exploited by the surrounding people. Utilization of water for domestic and irrigation purpose has intensified the demand of water for people living in towns of Haramaya, Awadey, Harar and local inhabitants and farmers around the lake area. As a result, water has been excessively abstracted from the lake and later from groundwater by the surrounding people.

Climatic changes are another change observed in the area of Lake Alemaya. Analysis of the meteorological data, namely rainfall and average monthly minimum and maximum temperature, showed that the climatic conditions in the area have changed in relatively recent years. For example, there is change in the total annual rainfall and shift in season of high rain fall in the area. While the beginning of the rainy season delays, the end of the rainy season is prolonged and extended to previously drier months. This has resulted in reduced harvest of crop by the local farmer, which in turn led to more dependence of the local community on the water of the lake for irrigation. On the other hand, the average monthly minimum air temperature in the Lake Alemaya area has shown increment in recent years than in previous years. As a result of the above changes the lake has undergone gradual reduction in volume and surface area and dried out completely in 2005. For example: the surface area and volume of the lake decreased from 5 km2 and 8.5m depth in 1965 to 0 in 2005.

Increased average minimum temperature and seasonal shifting of rainfall in the area has increased evaporation of water from the lake surface which in turn decreased the level of lake over time. The shrinking rate of the lake is found to be amplified overtime leading to its final vanishing. All these changes have contributed to the lake disappearance with its ecosystem services.

Impact of climate change and human activities on natural ecosystems has become a common place language. But the direct impact of human activities on natural ecosystems can be more important under some situations. This is the most important lesson that can be learned from this study. While climate change seems to result in the death of Lake Alemaya, the fact, however, is much more related with human activities than direct climatic impacts. Therefore, it is imperative to carefully consider human impacts in efforts to protect similar lakes in Ethiopia, which are mostly under similar environmental setting with Lake Alemaya. Moreover, information on ecosystem service help in educating and awaking society about the importance sustainable groundwater management, utilization, and planning alternative way of water source (supply) by policy makers and researchers.

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