Novelty Journals

ISSN 2394-7349

International Journal of Novel Research in Engineering and Science
Vol. 6, Issue 1, pp: (16-24), Month: March 2019 - August 2019, Available at: www.noveltyjournals.com

Impact of climate Change on Surface Water Resources of Ethiopia: A Review

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Abstract: **Ethiopia's water resources, as in many other regions of the world, are facing many challenges especially from climate change, which is one of the dynamic processes impacting water resources. Other processes such as population growth, increasing water demand, overexploitation of natural resources and environmental degradation have also significantly degraded the world's freshwater resources. This paper presents the nexus of water resources and climate change in Ethiopia. It uses the existing knowledge from relevant literature. It focuses on the water resource potential, trend and future projection of climate condition. Sensitivity of some specific water resources to current climate variability and future climate change are also discussed. Planned adaptation in the water sector and prospects for technological, infrastructural, social, institutional interventions that can improve future water resources management in an era of climate change are highlighted. Interventions that support the development of robust water resource systems that take water infrastructure options with emphasis on water storage are provided. Finally, the implications for future development and research are stressed.**

Keywords: **Climate change, Lake, River, Water Resource.**

1. INTRODUCTION

The impacts of climate change on water resources are high on the research agenda worldwide (IPCC 2007). Future changes in overall flow magnitude, variability and timing of the main flow events are among the most frequently cited hydrologic issues (Frederick 2002; Wurbs et al. 2005). Moreover water use has been growing at more than twice the rate of population increase in the last century, and, although there is no global water scarcity as such, an increasing number of regions are chronically short of water. By 2025, 1 800 million people will be living in countries or regions with absolute water scarcity, and two-thirds of the world population could be under stress conditions. The situation will be exacerbated as rapidly growing urban areas place heavy pressure on neighboring water resources (UN 2006).

Climate change is likely to aggravate the scarcity of water that is being driven by other basic forces. On one authoritative view, global warming of 2ºC would lead to a situation where "between 100 million and 400 million more people could be at risk of hunger, and 1 to 2 billion more people may no longer have enough water to meet their consumption, hygiene and food needs" (World Bank, 2009).

Climate change is severely impacting the hydrological cycle and consequently, water management. This will in turn have significant effects on human development and security (IPCC, 2007). Climate change will increase the number of people living in water stressed regions globally (Bates, 2008). In sub-Saharan Africa (SSA), the number of countries where water demand outstrips available resources is increasing. Many African countries experience either water stress or water scarcity or both. Moreover, food insecurity remains endemic throughout much of Africa, with climatic factors such as rainfall variability a major cause. For example, in 2006, 25 African countries required food aid, largely due to recurring drought and Ethiopia was one of the countries. Both observational records and climate projections provide strong evidence that freshwater resources are vulnerable, and have the potential to be strongly impacted.

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Climate change is expected to have adverse impacts on socioeconomic development in all nations although the degree of the impact will differ. The ICPP findings indicate that developing countries such as Ethiopia will be more vulnerable to climate change. Climate change may have far-reaching implications for Ethiopia due to various reasons. The economy of the country mainly depends on agriculture, which is very sensitive to climate variations. A large part of the country is arid and semiarid and is highly prone to desertification and drought. The country has also fragile highland ecosystem which is currently under stress due to population pressure. Forest, water and biodiversity resources of the country are also climate sensitive. Climate change is therefore a case for concern (NMSA, 2001).

Despite the fact that the impact of climate change is assessed and forecasted for different specific water resources of the country, impacts on water resources and water-dependent services have yet to be adequately addressed in either scientific analyses or water policy as the results of different studies are in fragmented manner.

2. OBJECTIVE

The objective of this paper is pulling together what is known about the links between climate change and water resources, drawing on the scientific literature.

3. WATER RESOURCES OF ETHIOPIA

Ethiopia is considered as water tower of Africa and endowed with a variety of aquatic ecosystems, especially a number of lakes that are of great scientific interest and economic importance. The total area of inland waters in Ethiopia is 8,800 square kilometers, representing 0.72 percent of the total surface area of the country (Greboval et al, 1994). Ethiopia has 12 river basins that provide an estimated annual run-off of 125 billion m^3, with the Abay basins (in central and northwest Ethiopia) accounting for 45 percent of this amount. While much of this run-off could be used for irrigation or other purposes, Ethiopia has limited water infrastructure to use this surface water.

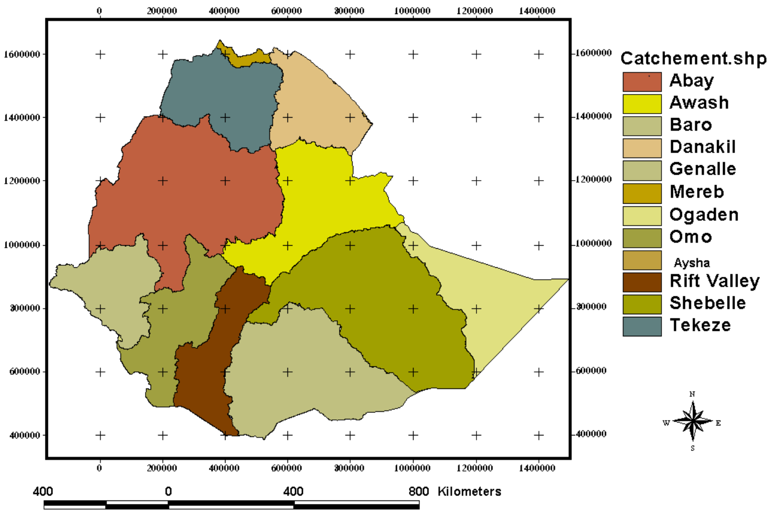

Figure 1: River basin of Ethiopia

CLIMATE OF ETHIOPIA

Climate is often described by the statistical interpretation of precipitation and temperature data recorded over a long period of time for a given region or location. Mean annual rainfall distribution over the country is characterized by large spatial variation which ranges from about 2000 mm over some pocket areas in the Southwest to less than 250 mm over the Afar and Ogaden low lands (NMSA, 1996, NMSA 2001).

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Rainfall during a year occurs in different seasons. Unlike most of the tropics where two seasons are common (one wet season and one dry season), three seasons are known in Ethiopia, namely Bega (dry season) which extends from October-January, Belg (short rain season) which extends from (February-May), and Kiremt (long rain season) which extends from June-September. Temperatures are also very much modified by the varied altitude of the country. In general, the country experiences mild temperatures for its tropical latitude because of topography. Mean annual temperature distribution over the country varies from about 10^0C over the highlands of northwest, central and southeast to about 35^0C over north-eastern lowlands.

Current Climate Variability and Observed Trends

Mean annual minimum temperature and annual rainfall variability and trend observed over the country in the period 1951-2006 are shown in Fig. 2 and 3, respectively. Annual minimum temperature is expressed in terms of temperature differences from the mean and averaged for 40 stations. Fig. 2 clearly reveals that there has been a warming trend in the annual minimum temperature over the past 55 years. It has been increasing by about 0.37 ^{0}C every ten years. The country has also experienced both dry and wet years over the same period as depicted in Figure 2. The trend analysis of annual rainfall shows that rainfall remained more or less constant when averaged over the whole country (Figure 2).

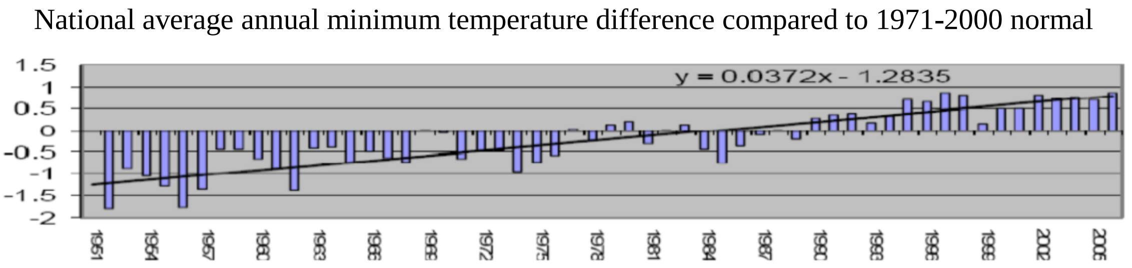

Figure 2. Year to Year Variability of Annual minimum Temperature over Ethiopia expressed in temperature difference

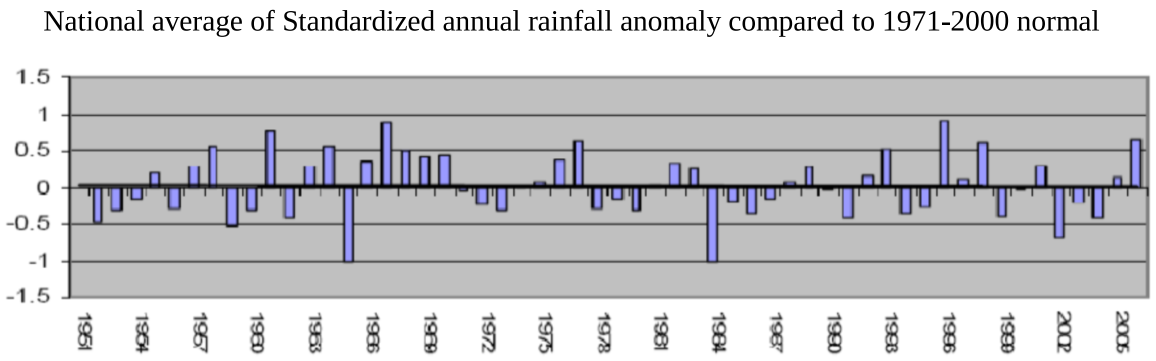

Figure 2. Year to Year Variability of Annual Rainfall and trend over Ethiopia expressed in Normalized Deviation

Projected Climate Change over Ethiopia

Projected climate change over Ethiopia Climate projections for Ethiopia have been generated using the software MAGICC/SCENGEN (Model for the Assessment of Greenhouse-gas Induced Climate Change) coupled model for three periods centered around the years 2030, 2050 and 2080. For the IPCC mid-range (A1B) emission scenario, the mean annual temperature will increase in the range of 0.9 -1.1 °C by 2030, in the range of 1.7 - 2.1 °C by 2050 and in the range of 2.7-3.4 °C by 2080 over Ethiopia (Figure 3) compared to the 1961-1990 normal. A small increase in annual precipitation is also expected over the country Abebe 2007 (Figure 4).

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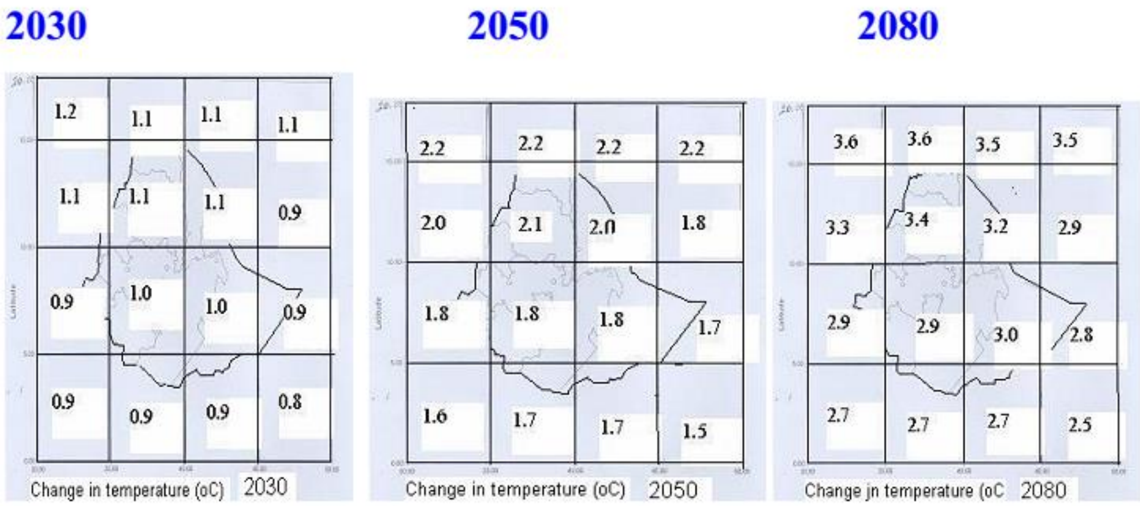

Figure 3: Composite (average of 19 GCMs) change in temperature (Co) relative to 1961 – 1990 normal for A1B emission scenario.

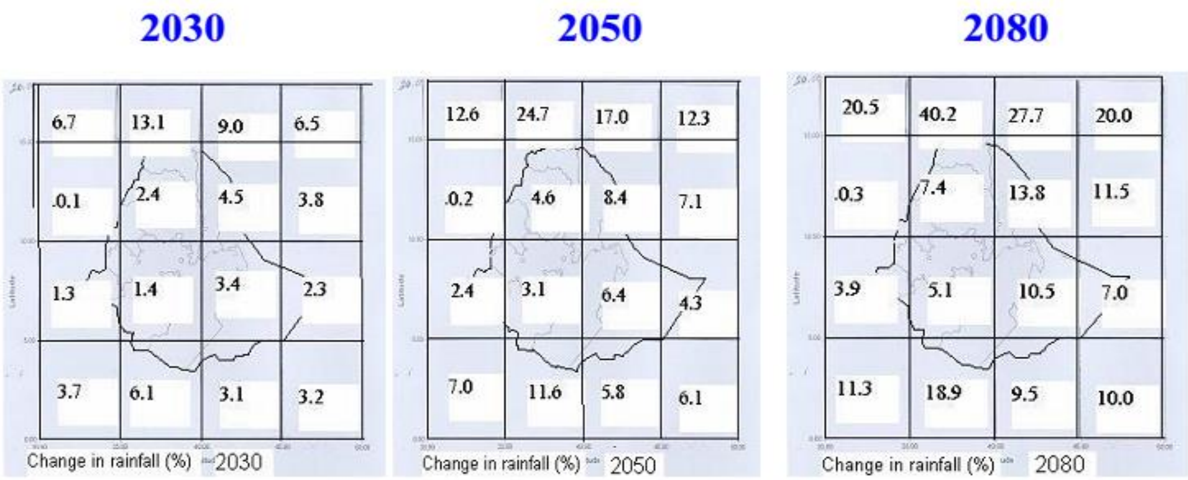

Figure 4: Composite (average of 19 GCMs) percentage change in (%) relative to 1961-1990 normal for A1B emission scenario.

Impact of Climate Change on Specific Water Resources

Ethiopia confronted many adverse impacts which are manifestations of variable climate. Yet there are indications by which these impacts will continue to influence the socio-economic activities of the community at larger scale.

The northern, southern and south-eastern dry land regions of Ethiopia have repeatedly faced increased frequency of meteorological drought episodes, famines and outbreaks of diseases which are believed to be linked with climatic change. The droughts have highly impacted the agriculture of the country and brought about the loss of crops, animals and above all the loss of millions of people. Flood hazards have increased in recent decades. The flood hazards which have occurred in different parts of the country in 1988, 1993, 1994, 1995, 1996 and 2006 are such indications.

The 2006 catastrophic flood led to the destruction of huge infrastructure and the death of more than 650 people and the displacement of more than 35,000 people in Dire Dawa, South Omo and West Shewa. Similar situations experienced over Afar, Western Tigrai, Gambella and over the low-lying areas of Lake Tana (NMA, 2007).

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Many studies have concluded that the water sector of the country is the most affected sector by climate change. Climate change that reduces either the overall quantity of water or the timing of when water is available for use will have important effects on agriculture, industrial and urban development.

Awash River Basin

An attempt was made to investigate the sensitivity of water resources to climate change in the Awash River Basin in Ethiopia using GCM and incremental scenarios by Hailemariam (1999). The results of the impact assessment over the basin showed a projected decrease in runoff, which ranged from –10 to –34%, with doubling of CO2and transient scenarios of CO2increase (GFD3, CCCM, GF01). Based on sensitivity analysis with incremental scenarios, he showed that a drier and warmer climate change scenario would reduce runoff. He concluded that areas where precipitation does not increase sufficiently to offset the temperature increase will have significant risk of drought.

Findings by Hailemariam (1999) indicate that the Awash River is highly vulnerable to climate change. He reported already a water stress has occurred due to population pressure even without climate change. Furthermore, he reported that 20% decrease in rainfall coupled with a 2°C increase in temperature would result in a 41% decrease in the annual runoff. Even a temperature increase of 2°C without precipitation change would result in a 9% decrease in annual runoff. On the other hand, an increase of precipitation by 10% would offset a 2 to 4°C increase in temperature and result in a surplus of runoff ranging from 4 to 12%. Hailemariam (1999) concluded that the general warming simulated by all GCMs under CO2 doubling would result in a substantial decrease in annual runoff over the Awash River Basin. Given the economic role of the river, climate risk will be too costly to be tolerated and urgent measures must be taken to mitigate the impacts adopting feasible strategies.

Abay River Basin

Figure 6 and Table 1 below summarize changes in key climatic and hydrological variables (basin average temperature, rainfall, potential evapotranspiration and flow at the Ethiopia-Sudan border) over the period 1983 to 2100 as derived from the CCLM and SWAT models. The models predict that for the A1B scenario, averaged across the basin, there will be: 1) an increase in temperature; 2) a decline in rainfall; 3) an increase in potential evapotranspiration; and 4) a decrease in flow at the border. As a consequence of the changes in rainfall and potential evapotranspiration, average irrigation demand (per ha) shows an increasing trend across the basin (Matthew P. McCartney 2012).

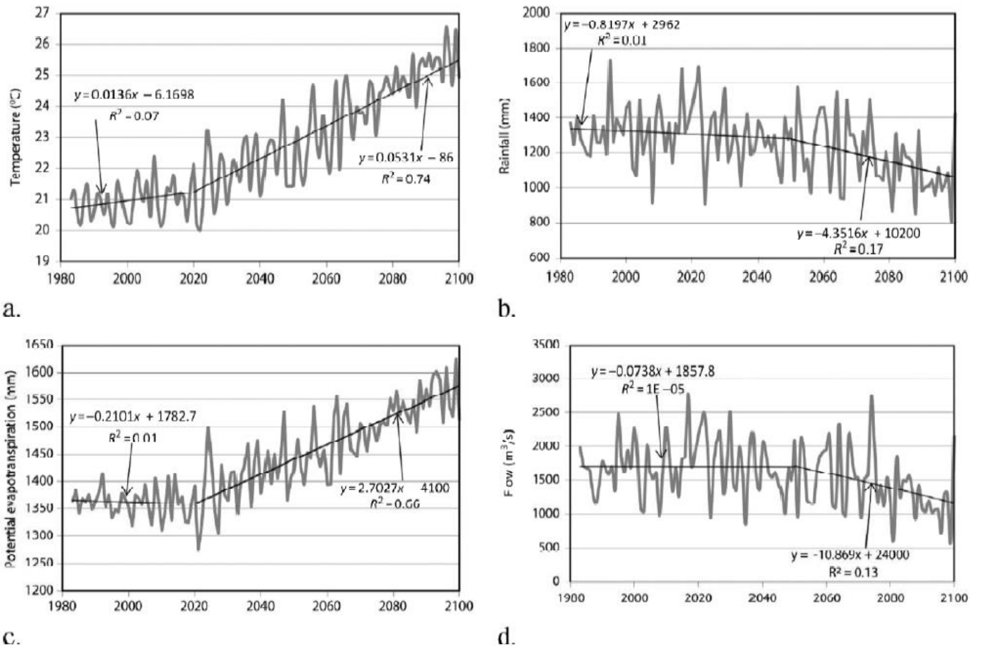

Figure 5: Basin average annual climate variables, 1083-2100: a, temperature; b, rainfall; c, potential evapotranspiration; d, flow at the Ethiopian-Sudan border.

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Table 1: Basin average climatic and hydrological variables for the three periods 1083-2012, 2021-2050 and 2071-2100

	Average annual temperature (°C)	Rainfall (mm)	Potential evapo-transpiration (mm)	Actual evapo-transpiration (mm)	Averaged annual flow at the Ethiopia-Sudan border (m^3/s)
1983–2012	20.9	1310	1,363	539	1661
2021–2050	21.9	1290	1,405	522	1720
2071–2100	24.9	1110	1,535	525	1336

Study based on CCCM, GFDL R-30, and UKMO-89 models climate change scenarios (Deksyos, 2000) indicates that basin to be highly sensitive to climate change. It was reported that runoff would decrease by 33.6% and 2.6% according to CCCM and GFDL R-30 models, respectively. According to UKMO projections, runoff changes would increase by 10%.

According to Deksyos, (2000), incremental climate change scenarios would decrease runoff significantly in warmer and drier scenarios over the basin. It is also predicted that even a temperature increase by 2°C without precipitation change would result in a significant decrease in runoff.

Gilgel Abay River and Reservoir

Yihun (2013) studied hydrological response of Gilgel Abay to climate using Statistical Downscaling Tool (SDSM) to downscale the HadCM3 (Hadley centre Climate Model 3) Global Circulation Model (GCM) scenario data into finer scale resolution and used as an input to SWAT model. He did the climate projection analysis by dividing the period 2010-2100 into three time windows with each 30 years of data. The results showed that annual mean precipitation may decrease in the first 30-year period but increase in the following two 30-year periods. The decrease in mean monthly precipitation may be as much as about -30% during 2010-2040 but the increase may be more than +30% in 2070-2100. The impact of climate change may cause a decrease in mean monthly flow volume between -40% to -50% during 2010-2040 but may increase by more than the double during 2070-2100. Climate change appears to have negligible effect on low flow conditions of the river. Seasonal mean flow volume, however, may increase by more than the double and +30% to +40% for the Belg (small rainy season) and Kiremit (main rainy season) periods, respectively. Overall, it appears that climate change will result in an annual increase in flow volume for the Gilgel Abay River. The increase in flow is likely to have considerable importance for local small scale irrigation activities.

Based on the study result of Habtom (2009) on climate change impact on Upper Blue Nile Basin Reservoir, the projected precipitation reveals an annual increase for all the three time horizons (i.e. 2020s, 2050s and 2080s) in A2a emission scenario, but for the case B2a emission scenario on average annual decreasing is observed during 2020s and 2050s while in 2080s the precipitation shows increasing trend. The evaporation from the open water generally shows an increasing trend i.e. it exhibits an average annual increase of 22 % for A2a emission scenario and 20 % increase for B2a at the end of the next century. This causes its own impact on the reservoir water balance by changing the reservoir volume.

Lake Tana

Climate change impact study was conducted on the water balance of Lake Tana by Zemede (2013). The study was conducted using HadCM3GCM employed for A2 and B2 emission scenario based on projection of three different scenarios of climate change for future time horizons: 2010-2039, 2040-2069 and 2070-2099. The result revealed that the maximum and minimum temperatures increase for the three scenarios in all the future time horizons and the over-lake evaporation shows increasing pattern for all future time horizons.

Lake Ziway/ Dembel

Lake Ziway, an Ethiopian Rift Valley Lake, has an open water area of $434km^2$ and average depth of 4 m. By applying changes of the climate variables to SWAT hydrological model to simulate future flows, Lijalem (2006) reported that, the scenarios developed for the years 2001-2099 showed that both temperature and precipitation are likely to increase from the 1981-2000 level. These changes are likely to have significant impacts on the inflow volume into the lake. Despite the increasing trend of both climatic variables, the increase in precipitation seems to be obscured by increases in temperature. Hence, the total average annual inflow volume into Lake Ziway might decline significantly. This is likely to drop the lake level up to two third of a meter and shrink the water surface area up to 25 km^2 which is about 6% of the base period water surface area. This combined with the unbalanced supply-demand equation in the watershed is expected to have significant impact on the lake water balance. Therefore, in Lake Ziway Watershed, runoff is likely to decrease in the future and be insufficient to meet future demands for water of the ever-increasing population.

Lake Haramaya

The previous Lake Haramaya was formulated from rainfall precipitation and drains along the catchments. In its hay days Lake Haramaya boasted a depth of 10-12m, before a decade the depth was 12 cm and currently no water at all. Lake Haramaya provided freshwater for drinking, irrigation, fishing, animal watering, general municipal uses and recreation to over 120,000 people of the region (Brook, 2003 and 1994).

According to Wagari (2005), and Tamiru et al., (2006), Lake Haramaya dried in 2005 mainly due to environmental degradation, as a result of deforestation and clearing of land for farming, which amplified the rate of siltation dramatically reducing the lakes' volume and surface albedo, which increased the rate of evaporation. Hence, excessive evaporation and dwindling precipitation has been the major impact of climate change in the Haramaya that affected direct recharge to the lakes. The decrease in the lake level due to evaporation could accumulate the salt at the bottom of the lake. Over-pumping has left white calcite precipitate on the dry lake surface. According to Wagari (2005), the high evaporation rate is due to the deforestation that has increased albedo, the increase of evaporative parameters such as temperature and wind speed that are aggravated by environmental degradation and alteration of lake basin such as clearing of vegetation in watershed and urbanization. In addition to excessive evaporation, decreasing trend of rainfall, and long dry periods has also been major factor that contributed the loss of the lake. According to Wagari (2005) the relative humidity is expected to be low, areas wind to be dry due to drying up of lakes.

Figure 6. Haramaya Lake from Hay day to vanish

The drying of the lakes have seriously affected urban residents of the three towns and the surrounding villages and livelihoods of people who depended on it for production food and cash crops, and hence has considerably affected their income and deepened their poverty. This has caused malnutrition and hunger. As well, it has resulted in population displacement.

4. CONCLUSIONS

Ethiopia has suffered the consequences of climate change and climate variability at various periods over the last century, the recurrence of the impacts has shown increasing tendency over the last 40 years. Observational evidences show that many vital water resources such as Lakes and rivers are decreasing. Though part of the cause may blame on the highly increasing demand, climate change/variability has shown putting significant pressure on the water resources.

In Ethiopia, climate change has the potential to impact negatively on water availability, stability, access, utilization, and demand. Recent studies also showed that the country is highly sensitive to changes in precipitation and temperature. As a result, river flows and runoff to lakes are likely to decrease in the future and be insufficient to meet future demands for water of the ever-increasing population in the country. Climate fluctuations also affect the use of agricultural land associated with irrigation; complicate the design, operation, and management of water-use systems. This in turn has the potential to disrupt livelihoods, increase poverty and the marginalization of the poor and escalate inequality. Many concerns and issues surround water resources are increasingly linked to climate change. Given the economic role of the water resources, climate risk will be too costly to be tolerated and urgent measures must be taken to mitigate the impacts adopting feasible strategies.

5. RECOMMENDED OPTIONS

Compounded with the level of poverty and population rise, the best adaptation option in is to improve adaptive capacity and resilience to vulnerability through:

- Strategic storage of water through soil moisture storage, artificial reservoirs and increasing productivity of water.
- Forecasting and early warning system of seasonal extreme hydrological conditions.
- Integrated watershed management by using appropriate technology at an appropriate location.
- Introducing new efficient technologies (for example, desalination, drip irrigation, wastewater reuse, recycling).
- Incorporation of climate risks into planning processes.
- Bringing together stakeholders and understand their complex functions and inter-relations in the context of climate change and variability.
- Relevant and practical research inputs are highly important to overcome gaps and deal with challenges in the process of managing natural resources and effecting quality water productivity.
- Investments in multipurpose water infrastructure, such as reservoirs, detention ponds, and small dams, have a high potential to address increased hydrologic variability by increasing water storage and regulating water flows.

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