Brief final Project Report
for
Global Change SysTem for Analysis, Research and Training (START)

Project title: Vulnerability of selected Ethiopian lakes to climatic variability, tectonism and water use

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1. The main objectives of the project:

Basically the project was intended to answer three major questions: 1) What is the relative importance of natural and anthropogenic factors in affecting lakes and their environmental repercussions? 2) What is the extent of the influence of these factors in time and space? 3) Regional and local changes and repercussions of the changes on the livelihoods of the society in the basins and beyond. It also intends to create working relations with expatriates out of Ethiopia and bring about their experience of similar researches in the East African rift, with particular reference to the Kenyan rift lakes through research visits.

2. Methodology and approach applied

Integrated approach has been employed spatially starting from regional, to sub-regional and local scale. At regional scale the chosen Ethiopian lakes are compared with the Kenyan lakes giving emphasis more on the hydrological balance, lake level changes and the hydrodynamics. This effort enabled to understand on how the natural and anthropogenic factors affect the East African lakes in a comparative manner. At regional scale the recent changes in the Main Ethiopian Rift has been assessed by considering six lakes which most of them are influenced by human activities and visible natural changes from recent neo-tectonic activities (Figure 1). At a local scale, two lakes were chosen for detailed assessment of the recent changes due to climatic and water use changes (Awassa and neotectonic activities (Ziway and Awassa).

The selected lakes are located in a hydrogeologically complex rift environment where many natural and anthropogenic factors played important role in changing the size and level of most of the rift lakes. In such a complex rift environment it is prudent to apply a converging evidence and integrated approach. The methods used include correlation of lake levels with climatic factors and water use, water balance study, remote sensing and GIS application, field hydrological and hydological investigations.
Ancillary information was obtained from hydrochemical and environmental isotope studies. Water samples were collected and analyzed in the analytical laboratory of the Department of Earth Sciences, Addis Ababa University. The samples are for major ions and cations, and environmental isotopes of $^3$H, $^2$H and $^{18}$O. The stable isotope data has been extracted from existing data base of IAEA. The instruments used for the water sample analysis include ion chromatograph, atomic absorption spectrophotometer and tritium scintillator. Common water chemistry in situ measurements have been made in the field. These include pH, EC, TDS and temperature. For spatial analysis of land use and lake level changes thematic mapper image taken in 1987 and 2004 have been used. These images provided local and regional view of changes in the size of lakes and catchment land cover. Detailed structural survey was conducted to map the major geological structures related to more recent tectonics affected the hydrogeological setting.

A comprehensive hydrometerological and hydrogeological database has been developed. The data basin includes climatic (rainfall, temperature, pan evaporation, sunshine hours, wind speed), hydrologic (river discharges, lake levels) and hydrogeological (hydrogeological maps, piezometric levels, well logs, etc.). For lake Awassa with detailed information, a simple hydrological model was applied using recent data to see the

Figure 1. Simplified location map of the studied areas including major Ethiopian lakes
sensitivity of the lake to different catchment factors. The same method has been applied to the Kenyan lake Naivasha.

2. Outcome of the research

Aside from the comprehensive development of the hydrometrological and hydrogeological database, the work provided very important scientific results. The research provided basic information (in the form of attribute tables, maps, graphs and processed images) as to how the various factors affect the rift lakes. The results presented here with this report are in the form of publishable manuscripts (submitted and being submitted soon to reputable international journals) and additional illustrative charts and images shown recent neotectonic activities. Please find attached with the various manuscripts and illustrations of the result of the research. The Kenyan lakes case is related to the work done with the staffs of the host institution when the project leader was in the Netherlands as per the research proposal presented to START. The documents include:

1. Environmental Changes in the Ethiopian Rift. This paper is submitted to the Journal of Lakes and Reservoirs: Management and Research (under review).
3. Comparative assessment of the hydrology of selected Ethio-Kenyan lakes. This paper is soon to be submitted to Hydrological Sciences Journal. I am waiting some data on hydrochemistry of Kenyan lakes from ITC.
4. The relative importance of climatic and anthropogenic factors on the recent decline of the level of Lake Ziway.
5. Illustrative pictures and images showing neotectonic features and lake size changes.

3. Major conclusions made from the research and recommendations

From the research the following important scientific conclusions and recommendations can be made.

- The water balance study revealed that rainfall, flux from surface waters are the main components of the water balance of most lakes. Despite the classical common assumptions, groundwater plays a vital role in most of the lakes in the rift valley. This is particularly the case for terminal lakes at lower elevations. The research clearly demonstrated that any management plan of the lakes without
addressing the groundwater component would lead to erroneous water management practices.

- The detailed study carried out in the lake Ziway catchment provided very important result on how the various components of the hydrologic cycle affect the lake. It was found that highland rainfall is the driving force of the hydrology of the rift lakes. The result also shown trends of reduction in rainfall and rise in evaporation. This change with dramatic rise of water use affected the lake dramatically, especially after 2000.

- The integrated study of the Ethio-Kenyan rift revealed that the lakes are hydraulically connected in the subsurface. This indicates that any future management should bee seen in integrated manner by accounting all such lakes as a single hydrological system. Affecting one lake will result a negative consequence on other lakes also.

- Despite a slight decline in rainfall and rise of temperature, the river discharge record shows locally an increasing trend indicating increase in the runoff owing to substantial deforestation in during the past three decades.

- The hydrogeological field mapping clearly demonstrated that the rift valley floor faults and marginal normal open faults play a vital role in transferring or hindering groundwater going into and out of the lake. These faults divert substantial groundwater parallel to the axis of the rift diverting groundwater from
one catchment into another catchment at the expense of some lakes. The most notable example to this is the transfer of groundwater from lake Ziway catchment to Langano and finally to Shalla and the movement of groundwater from lake Awassa to Shala. This shows that many lakes although, topographically closed, they have hydraulic links to other lakes in adjacent catchments. The most beneficiary from the rift faults are those located at relatively lower terminal position. In this connection both the Ethiopian and Kenyan lakes have striking similarity.

- Many of the level of the rift lakes fluctuate according to the precipitation trends in the adjacent highlands. However, the drastic changes occurred after the commencement of large-scale water abstraction. Lake Abiyata reduced in size by about 23 percent for the last forty five years as a result of lake water evaporation for soda extraction and upstream irrigation. Lake Beseka has expanded drastically (37 km² in about 40 years time) due to the enhancement of recent groundwater recharge caused by very high infiltration from nearby over irrigated fields and transmission losses in high water level rise of the Awash river affected by upstream damming. The formation of new faults is likely to play a positive role; although the evidence is not as clear as the catchment of Awassa.

- Improper utilization of water resources resulted in substantial changes in the hydrological setting of lakes Ziway, Abiyata and Beseka. These problems are more pronounced in terminal lakes without surface water outlets.

- Recent tectonic activities have dramatically changed the hydrogeological setting of some of the lakes in the Ethiopian rift. These changes are manifested in the form of disappearance of swamps, ponds, small lakes, springs and geysers. At the expense of the disappearance of these small water bodies at higher altitudes some
rift lakes rise in level. The most peculiar example to this is Lake Awassa and Beseka. The effect of neotectonism is not clearly visible in the Kenyan rift lakes.

- This research illustrated the existence of active tectonic activity changing the hydrogeological setting which is the most interesting aspect of the hydrodynamics in relation to the hydrogeology of the extended rift that may attract many researchers working in active tectonic environments elsewhere. The issue of the impact and variations in space and time of the hydro-geodynamics can be addressed in detail by monitoring of lake beds with seepage meters, measurement of extension or movement of rift faults, dynamic topographic surveying and application of tracer techniques.

- Any study aiming at the implementation of sustainable lake water use should not consider lakes as separate hydrological entities as they are strongly influenced by the surface water and groundwater inputs and outputs. Particularly any environmental impact assessment of the abstraction of water from Abiyata should be seen together with lakes Ziway and Langano. Attempt to quantify the water budget by taking the surface water divide of each lake will certainly bring about erroneous results in almost all lakes. One has to consider how these lakes are interconnected in the subsurface.

- Generally, the current and likely future uncontrolled water extraction will have obvious repercussions, which will bring grave consequences to the rift environment in the near future. This demands a comprehensive water management and planning strategy requiring the process of protecting and developing the water resources in a broad, integrated, and foresighted manner. In practice, this is a complicated endeavour, since comprehensive water management involves a number of functions that are closely related but which are carried out by different agencies and organizations.

4. Environmental repercussions
Lake Abiyata is a shallow highly productive alkaline lake whose muddy shore supports a wealth of bird life almost unequalled perhaps in the whole of Africa; as such it is of great biological importance play an increasing role in the promotion of tourism. The high density of flamingo in the lake is able to subsist directly on the blue-green algae in the surface waters while many other birds are dependent on fish. Due to very high alkalinity, lake Shala lacks the fish necessary to support such concentrations of fish eating birds. Therefore, they depend on the fish population in Abiyata. The higher temporal changes of the alkalinity of the lake will result in reduction of population ultimately leading to the death of fish-eating birds. Reduction in the volume of lake Ziway could be expected to increase the ionic concentration of the water as in the case of Abiyata, which will have grave consequences on the fragile aquatic ecosystem.

With broad shallow margins fringed with swamp, dense floating vegetation and a high concentration of phytoplankton, lake Ziway supports the heaviest fish stock in the region and is the principal source of commercial fishing in Ethiopia. Therefore, the main economic consideration of altering the volume of Ziway for irrigation is the impact on its considerable potential as a freshwater fishery. The other more subtle effect of lake level reduction is on the vegetation around the lake edge, which plays an important role in providing food and shelter for numerous animals. Some species are apparently sensitive to short-term fluctuations and disruptions to their environment, including the marginal vegetation. The existence of a wide variety of bird life around the lake Ziway makes it more scenic. Irrigation around the lake and deforestation have already been profoundly affected the larger mammalian population. The terrestrial flora and fauna around Lake Ziway depends on the ecological integrity of the lake for its sustained functioning.

The alarming rise of the level of Beseka has multiple effects. The highway and railroad, Ethiopia’s sole access to the harbor, pass just near the northern shore of lake Beseka. The lake water threatens this access more and more each rainy season. The problem has been overcome temporarily by constructing embankment to elevate the access; and recently by pumping the lake water into the nearby Awash river. If lake Beseka breaks the natural water divide it will invade the surrounding small town before it joins the Awash river. The mixing of the alkaline lake with the fresh Awash river will also affect the hydrochemistry and the aquatic ecosystem downstream. The rise in the salinity of the river water will also have negative implications on the downstream irrigation fields which depend on the river water. The blended water may recharge shallow groundwater systems in the dry Afar region which provides potable water for millions of people.

Improper irrigation practises may also result in an invasion by both plant and disease causing organisms. These have proved more difficult to remedy than many problems related to irrigation. For example, a sombre aspect of the valuable contribution of irrigation activities in many places is the increase in the incidence of bilharziasis in the human population. Uncontrolled irrigation close to lake Ziway may favour the introduction of Schistosoma mansoni (bilharzia).

The highlands where major feeder rivers come to the MER are highly cultivated areas and source of lake sediment and fertilizers. The use of fertilizers is growing from time to
time. Scientific data were not existent; the common sense understanding is that rapid utilization of fertilizers increases the rate of supply of nutrients into the lakes. If the proposed large-scale irrigation projects in the Maki and Katar valley are going to be fully implemented this problem is eminent. The notable effect of high nutrient in lakes is eutrophication, which simulates the growth of algae or rooted aquatic plants which causes in the interference with desirable water uses of aesthetics, recreation, fishing and water supply. The incrustation of significant quantities of elements derived from fertilizers could markedly influence the population of phytoplankton and have major long-term effects including: (1) changes the odour and colour of water; (2) phytoplankton and weeds settle to the bottom of the water and create a sediment oxygen demand (SOD) which lead to low dissolved oxygen (DO) in lake waters; and (3) extensive growth of rooted aquatic macrophytes (larger plant forms) interfere with navigation and aeration problems.

The valuable bird fauna of the region is rapidly declining in terms of its diversity, distribution and abundance. This means that all the scientific, ecological, social and economic benefits we expect from the presence of the bird fauna will not be there if we fail to conserve the diversity, distribution and abundance of birds of the region. The major causes for the bird fauna decline are the terrestrial and aquatic habitat degradation and the reduction in the diversity, distribution and abundance of the terrestrial and aquatic plants and the fish fauna of the lakes in the region. Removal of Acacia trees for charcoal and fuel wood production from the Abiyata-Shalla lakes area also affects the breeding and feeding sites of the internationally important migratory birds.

5. Impact of the project nationally and internationally

At a national level some of the output of this research has been presented in two national conferences and has been appreciated. In the near future effort is being made to establish a management work plan by the local governments for future sustainable and environmentally sound utilization of lakes Ziway and Abiyata. The output of this research will provide basic information to such an effort. Owing to the ever-growing abstraction of water and lake level changes, the Ethiopian government has a plan to conduct detailed master-plan study of the rift valley ultimately to exercise integrated water management in selected basins. Such an effort requires assessment of the relation of the lacustrine system with all possible influencing factors including man-made and natural. This study certainly will play a positive role in this national effort.

The data base (maps, raw data, calibrated model) will be used in teaching hydrogeology and hydrology students in the Department and the university of Addis Ababa at large by using indigenous data which can be illustrated with field visits.

This research paved the way for future regional scientific cooperation among Addis Ababa University, the Egerton University in Kenya and the International Institute for Geo-Information Science and Earth Observation (ITC) from the Netherlands. The research visit of the project leader to ITC enabled both to assess the Ethio-Kenayan lakes.
At this stage the detailed study of the geo-hydrodynamics of the vast rift system as a whole is quite difficult and ambitious. But, the correlation of the Ethio-Kenyan lakes is believed to establish the foundation for large-scale integrated scientific research in the East African rift system in line with the scientific agendas, activities, and projects of IGBP, IHDP and WCRP. This research is in fact in line with the projects of IGBP, IHDP and WCRP as it mainly focuses on climatic variability, vulnerability and impact of hydrological systems. The Ethiopian rift has not been studied as such under these projects. The data generated in this research scheme from the poorly understood region as the Ethiopian rift will provide basic information for future global change research in the East African rift system as a whole.