Sustainable systems

Current ecological scenario of some Rift Valley lakes of Ethiopia: A review

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https://doi.org/10.59411/yjc60r43

Contents

How to Cite:

Abera, L. (2023). Current ecological scenario of some Rift Valley lakes of Ethiopia: A review. *Sustainable Systems*, *6*(2). https://doi.org/10.59411/yjc60r43

ABSTRACT

Lakes Ziway and Abijata are found in the Central Ethiopian Rift Valley and form a complex and vulnerable hydrological system with unique ecological characteristics; they are well-known for their biodiversity. The most important components of the water resources of the lakes are precipitation and river inflow and the lakes are used for smallholder to large scale agriculture, domestic water use, fishery, industrial water use and associated eco-tourism. Due to the suitability of environmental conditions and other infrastructures in the area, different organizations have started development projects in the area. The major threats that are common and need due attention are water use conflict; unplanned land use; pollution; deforestation; urbanization and population migration for the demand of resources; wetlands fragmentation and others. Recent water abstractions for irrigation and soda ash production have drastically changed both the lake level and its ecology. Thus, issues of appropriate management systems are urgently needed for sustainable development of the resources.

Keywords: Ecology, lake level, Lake Ziway, Lake Abijata, water quantity.

1. Introduction

The Ethiopian Rift Valley, also known as the Afro-Arabian Rift, is a prominent segment of the Great East African Rift. Stretching from Jordan in the Middle East through East Africa to Mozambique in Southern Africa, it extends from the Kenya border to the Red Sea. This geological marvel divides the Ethiopian Highlands into northern and southern halves. The formation of the Ethiopian Rift Valley can be attributed to volcanic and faulting activities, leading to the creation of volcano-tectonic depressions in the rift floor that eventually transformed into lakes. Three major water basins traverse the rift valley from northeast to southwest: the Awash basin with lakes Koka, Beseka, Gemari, and Abe; the Central Ethiopia Rift (CER) valley with lakes Ziway, Langano, Abijata, and Shala; and the Southern basins with lakes Hawassa, Abaya, Chamo, and Chew-Bahir (Halcrow, 1989).

The Central Ethiopian Rift valley stands out with its chain of lakes and wetlands boasting unique hydrological and ecological characteristics. The region faces growing pressure from population expansion and economic developments, placing a heightened demand on its valuable freshwater resources. Historically, the lakes supported agriculture, commercial fishery, domestic use, industrial soda extraction, and recreation, while the lakes and surrounding wetlands nurtured a diverse range of endemic birds and wildlife. The intricate interplay between development activities and their impact on biodiversity presents both advantages and disadvantages. Consequently, the primary objective of this paper is to evaluate the current environmental status of Lake Ziway and Abijata.

2. General Overview of the Lakes

Lakes Abijata and Ziway, situated in the Ziway-Shala basin in Central Ethiopia (Fig. 1), are characterized by their relatively shallow depths. The climate in the highlands ranges from humid to sub-humid, while the rift valley experiences a semiarid climate. The mean annual temperature is approximately 15°C in the highlands and 20°C in the rift valley. Annual rainfall varies from 1150 mm in the highlands to 650 mm in the rift floor (Tenalem Ayenew, 1998). The primary rainy season spans from June to September, with the dry season extending from October to February (Dagnachew Legesse et al., 2004).

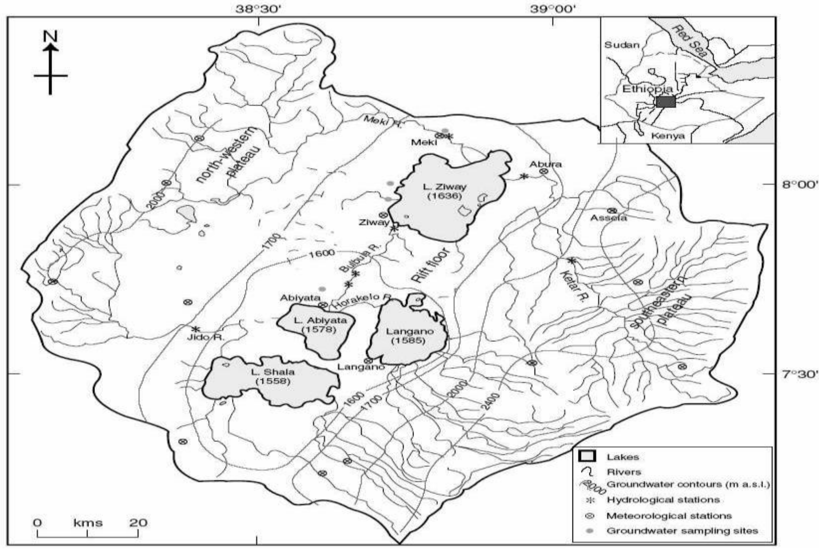

Fig. 1. General location map, topography, and drainage pattern of the Central Ethiopian Rift lakes (Dagnachew Legesse, *et al.*, 2004).

The lakes are situated in mid-altitude regions, with mean annual rainfall varying within the valley from approximately 500 mm (at the weather station at Lake Langano) to 650 mm (at the weather station at Lake Ziway), and up to 1150 mm on the plateau. Over the past 40 years, there has been no discernible trend, either an increase or decrease, in rainfall characteristics in the region (Alemayehu Negassa et al., 2006). The highlands surrounding both lakes play a crucial role in intercepting most of the rainfall in the region. Open water evaporation (lake evaporation) ranges between 1800-2000 mm per year, while actual evapotranspiration varies from 700 to 900 mm per year depending on land use and water availability (Tenalem Ayenew, 2003).

2.1. Ecology

The Central Ethiopian Rift (CER) valley is renowned for its biodiversity. The area's vegetation is characterized by Acacia open woodland, which has been extensively overgrazed, and deciduous forests occupying the ridges and slopes (Vallet-Coulomb et al., 2001). High human pressure in the rift valley has led to the rapid disappearance of natural flora and fauna. Increased human activity has resulted in floristically poor and uniform open vegetation, conversion of natural vegetation, overgrazing of grasslands, removal of shrubs for firewood, and clearing of forests for construction materials. Consequently, vulnerable sloping areas experience heightened erosion and nutrient depletion necessary for vegetative growth. The increased erosion and sedimentation pose significant threats to regional hydrology (Feoli and Zerihun Woldu, 2000).

Approximately 50% of Ethiopia's bird species have been recorded in the rift valley area. Current commercial fisheries cover a significant portion of the country's freshwater resources, including Lake Ziway, which was one of the most intensively fished lakes in Ethiopia in the 1960s, with an estimated annual production of 3000 tons. However, recent data suggest a reduction in production due to human influences. In Lake Abijata, there is no significant commercial fishing.

2.2. Water Quantity

As depicted in Fig. 2, the lakes receive water from various sources, including rainfall. However, due to varying infrastructural suitability, the water resources are currently over-exploited, particularly through irrigation and water extraction.

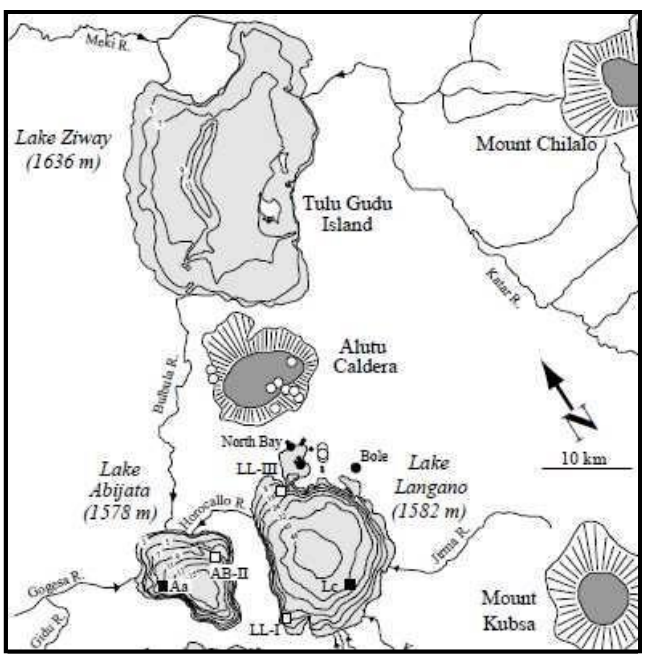

Fig. 2. Different water sources of Ziway-Abijata Catchment (Turdu et al. 1999)

Lakes Ziway and Abijata are situated in a closed basin, with the major incoming rivers for Lake Ziway being Ketar and Meki Rivers (Fig. 2). River Meki drains runoff from the Guerague Mountains west of Lake Ziway, while River Ketar discharges water from the eastern and southeastern Chilalo Mountains, covering a combined catchment area of 5610 km² (Dagnachew Legesse et al., 2004). Lake Abijata receives a significant portion of its water from Lake Ziway through River Bulbula, establishing a hydrological connection between the two lakes. However, Lake Langano contributes considerably less water to Lake Abijata through River Hora Kelo (Fig. 2).

The groundwater system in the Ziway/Abijata catchment is influenced by the East African Rift Valley, a major structural feature with a width of 40-60 km and depths reaching up to 1000 m below the flanking plateaus. Groundwater flow is directed toward the lowest point of the Ziway/Abijata catchment, contributing approximately 20% of the total inflow into Lake Abijata (Vallet-Coulomb et al., 2001). Rift faults largely control the groundwater, serving as a significant source for domestic water supply and supplementing Lake Ziway's surface water.

2.2.1. Lake Ziway

Lake Ziway has a maximum depth of 9 m, with an average depth of 2.5 m and a volume of approximately 1.1 billion m³ (ILEC, 2001). It primarily receives freshwater from the perennial rivers Ketar and Meki, as well as rainfall. Base flows from these rivers have diminished due to uncontrolled water abstractions for small-scale irrigation in the upper catchments. Only a small portion of the inflowing water is discharged to Lake Abijata through the natural outlet, River Bulbula, estimated at around 10% under natural conditions. However, this discharge has reportedly decreased in recent years (Amare, 2008).

2.2.2. Lake Abijata

Lake Abijata has a maximum depth of 13 m, an average depth of 7.6 m, and a volume of approximately 750 million m³ (ILEC, 2001). The lake's average depth is roughly three times that of Lake Ziway. Since 1985, the lake level has decreased by about 5 m due to increased water abstractions and changes in land use. Water consumption for domestic use and small irrigation schemes along the Bulbula River is estimated at about 59 million m³, approximately 38% of the mean annual discharge of River Bulbula over the past 30 years. Additionally, annual water use for soda extraction from Lake Abijata through an artificial evaporation basin is estimated at 2.25 million m³ (Legesse et al., 2004) and 15 million m³ (Tenalem Ayenew, 2004).

2.3. Water Quality

2.3.1. Lake Ziway

Lake Ziway is a freshwater lake with low salt concentration. Total dissolved solids range between 200 and 400 mg/l, and pH is neutral to slightly alkalic. The predominant ions in Rivers Meki and Ketar are calcium and bicarbonate. The water composition in the Bulbula River and Lake Ziway shows relative abundance of sodium and bicarbonate, attributed to the dissolution of sodium-containing rock minerals. Silica concentrations in Lake Ziway are lower than in the rivers, likely due to the lower temperature of the lake compared to the inflowing rivers and the extraction of silica by organisms.

2.3.2. Lake Abijata

Lake Abijata is a saline, soda-type lake typical of the Rift Valley, with a pH around 10. The water exhibits increased salinity and alkalinity due to evaporative conditions and contributions from hot springs. Salinity ranges between 12000 and 24000 mg/l, and there has been a substantial increase in salinity and alkalinity over the years, likely attributed to increased water extraction along the Bulbula River and soda ash production.

3. Mean Monthly Discharge

3.1. River Meki

On an average monthly basis, maximum flows in River Meki occur in August with a minor secondary peak in April, while minimum flows are observed between December and February (Fig. 3). The hydrograph indicates that the river bed may dry during December-January, emphasizing the dependence on river runoff for irrigation and domestic water supply throughout the year. The total annual contribution of River Meki to Lake Ziway is 277.81MCM (Amare, 2008).

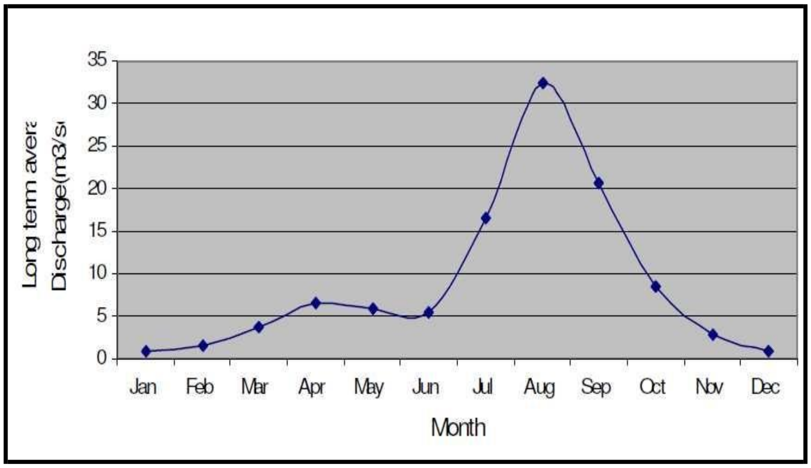

Fig. 3. Mean monthly River Meki discharge

3.2. River Katar

River Katar, boasting a substantial catchment area of 3400 km², originates in the Arsi highlands to the east of Lake Ziway. Consequently, the river maintains a generally steep gradient throughout its course to the lake and is often deeply incised up to 50 meters below the surrounding terrain. As highlighted by Tenalem Ayenew (2004), the hydrograph of the river exhibits notable variations at two key stations. The discharge measured at Katar Fitee (Sagure) surpasses that at Katar Abura, a distinction particularly pronounced during the high rainfall months, such as August (Fig. 4).

This disparity in discharge between the two stations during high rainfall months is attributed to potential abstractions, either through faults or evapotranspiration processes occurring between the observation stations. Conversely, discharge measurements at the two stations show comparable values in the months of October and November. The annual inflow of Lake Ziway from the Katar River is recorded at 401.3 million cubic meters (MCM) at Abura (confluence to Lake Ziway) and 562.20 MCM at Katar Fitee, situated midway along the Katar River (Amare, 2008).

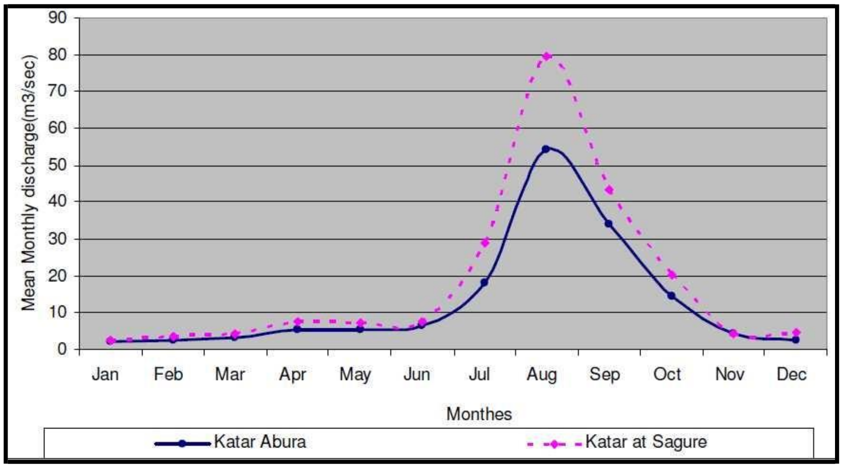

Fig. 4. Comparison of mean monthly River Katar discharge at Abura and Sagure

3.3. Bulbula River

The overall discharge of the Katar River seems to be on a decreasing trend. While its flow pattern is comparable to that of the Meki, Katar's peak flows are more distinct, and base flows during dry seasons are notably higher. Despite these similarities, it appears unlikely that the Katar River would completely dry up.

3.4. Bulbula River

All outflow from Lake Ziway is conveyed by the Bulbula River, which travels south for 30 km before reaching Lake Abijata, a terminal lake. With exceptions during the wet season, the Bulbula's flow primarily originates from Lake Ziway, although it has significant catchments with intermittent tributaries from the east contributing sporadically.

The mean monthly discharge of the Bulbula River at Kakarsitu, in actuality, should be greater than that at Bulbula town, especially during the rainy seasons due to additional runoff from ephemeral rivers between the two stations. However, as depicted in Figure 8, the discharge observed at Kakaritu station is consistently greater than measurements taken at Bulbula town throughout the observed years. This discrepancy is attributed to river losses, abstractions along the river stretch, and evaporation even during the rainy seasons.

The total mean annual outflow from Lake Ziway, measured at Kakarsitu and Bulbula Town, is reported as 161.33 MCM and 127 MCM, respectively (Amare, 2008).

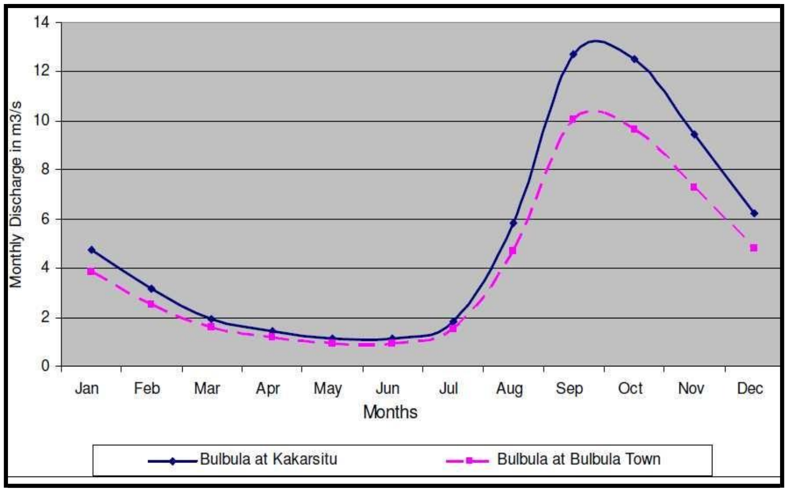

Fig. 5. Mean Monthly River Bulbula discharge at Kakarsitu and Bulbula town

3. Lake levels

The physical regimes and levels of lakes are subject to various natural and anthropogenic factors, including climatic, hydrological, and man-induced influences (Nicholson et al., 2000; Sene, 2000; Yin et al., 2000). Changes in lake levels are a consequence of shifts in the water balance or the steady-state removal of water through surficial and subsurface processes. Closed terminal lakes, in particular, exhibit significant fluctuations in response to climatic changes but generally maintain equilibrium between input and output (Tenalem Ayenew, 2002).

Certain Ethiopian Rift lakes, especially those in terminal positions, have experienced notable level changes since the 1970s. Over the last few decades, the escalating utilization of water resources in the rift and adjacent highlands has led to salinization of irrigation fields and fluctuations in lake levels (Hailu et al., 1996; Tenalem Ayenew, 1998).

3.1. Lake Ziway

Lake Ziway's water level is unregulated, with reported annual fluctuations of 0.8 meters, occasionally reaching up to 2 meters (Tenalem Ayenew, 2004; Welcomme, 1972). Current total surface water abstraction from the Ketar River and Meki River for irrigation is around 28 million m^3 per year (Tenalem Ayenew, 2004). Due to sedimentation issues, the mean annual water level time series may appear to be increasing. However, after adjusting for sediment deposition using bathymetric surveys from 1976 and 2005/2006, the annual water level time series actually indicates a decreasing trend.

3.2. Lake Abijata

Lake Abijata's level is strongly influenced by inputs from Lake Ziway through the Bulbula River. Monthly gains to storage are meager, usually less than 5% in most dry months. Significant volume reduction occurred in 1985 and 1990, amounting to about 425 x 10^6 m^3, or 51% of its present volume (Tenalem Ayenew, 2002). The reduction in Lake Abijata's level correlates with changes in its ionic concentration (Wood and Talling, 1988).

Overall, Lake Abijata's level fluctuates based on precipitation trends in the highlands. The recent drastic decline and increased salinity align with large-scale water abstraction. Uncontrolled future water abstraction is anticipated to have severe environmental consequences, especially when considering its interconnectedness with Lake Ziway's irrigation.

4. Impact of Decreasing Lake Ziway Level on Lake Abijata

If all proposed irrigated areas are developed, with an estimated annual water requirement of 365.9 MCM, Lake Ziway's level would decrease by 0.822 meters. This reduction, -0.24 meters below the level to which the Bulbula River flows to Abijata, would lead to a significant drop in Lake Abijata's level and potentially result in the drying up of the feeder Bulbula River, a crucial source of domestic watersupply (Fig. 6).

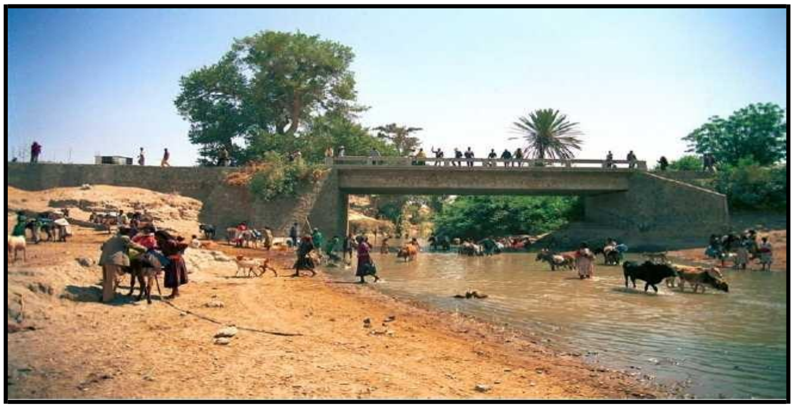

Fig. 6. River Bulbula as potable water source for domestic users

The apparent decreasing of Abijata lake level and Bulbula runoff is parallel which shows that the Abijata Lake level depends on the Bulbula runoff which spills out from Ziway Lake.

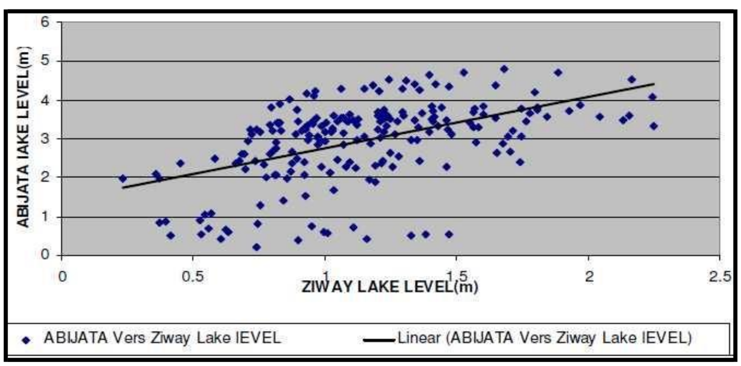

Fig. 7. Abijata versus Ziway Lake Level (Amare, 2008).

Hence, the level of Lake Abijata is strongly influenced by the input from Lake Ziway, facilitated through the Bulbula River. Consequently, any decrease in the inflowing water discharged from Lake Ziway to Lake Abijata will directly impact the environment. Changes in land use and heightened water abstractions along the Bulbula River have led to diminished inflows to Lake Abijata, resulting in lower water levels, and an increase in lake water salinity and alkalinity (Fig. 7).

5. Conclusion and Recommendations

This review focused on the current situation of the lakes, particularly examining the potential impact of Lake Ziway on Lake Abijata. Surface water extraction for irrigation, industrial, and domestic purposes is consistently on the rise in the CER valley. The limited available data suggest that the sustainable limits of water extraction have been surpassed.

The scenarios of abstraction in the Ziway-Abijata Lake watershed not only affect Lake Abijata but also impact domestic water users along the river, as it is the sole freshwater source between the two lakes. Therefore, the following recommendations are proposed:

1. Conduct a detailed resource assessment of water, encompassing sustainable abstractions and considering the special variability of water quality and quantity.
2. Implement measures to reduce water loss due to evaporation in lakes.
3. Given the depletion of large trees for fuelwood and charcoal production, planting tall trees on the windward side of the reservoir is advised to act as windbreakers and reduce evaporation.
4. Develop a program for erosion control measures in the basin and provide environmental education to the community through various associations, organizations, schools, etc.
5. Integrate irrigation activities into a comprehensive approach to sustain future development activities based on lake water resources.

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