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Current Status and Threats of Lake Abijata to reveal the conservation challenges of wetland resources in case of Abijata Shalla Lakes National Park, Ethiopia

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ABSTRACT
This study was conducted at Abijata Shalla Lakes National Park (ASLNP), Ethiopia, to examine Current Status and Threats of Lake Abijata to reveal the conservation challenges of wetland resources in the central Great Rift Valley, Ethiopia. The aim was to identify the conservation challenges facing the wetland resources of the central Great Rift Valley and to provide relevant information for informed decision-making on feasible management interventions to protect this nationally and globally significant rift lake wetland. Structured questionnaires were prepared to collect data on hydrology, land use, water quantity, water consumption, and environmental rehabilitation and management. Interviews and extensive discussions were held with the respective stakeholders. The collected secondary literature was thoroughly reviewed and analyzed. The main threats that could negatively impact the lake include overgrazing, deforestation in the upper catchment area, the abstraction of lake water for soda ash mining, upstream water abstraction, especially from the Bulbula River, and the potential drying up of the lake due to a drop in its water table. Effective stakeholder engagement provides relevant parties, including sub-basin water users, with opportunities for intensive involvement in the planning, decision-making, and evaluation of all activities related to the preparation and implementation of the Lake Watershed management plan. Therefore, significant attention must be given to conserving these lake wetland resources through in-situ conservation and sustainable park management, utilizing an integrated and participatory natural resource management system.
Key words: *conservation, rift valley, terminal lake, wetland, watershed, upper catchment*

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INTRODUCTION

The wide diversity of landscapes of the Central Great Rift Valley (CGRV) and ecosystems comprises extensive biodiversity-rich wetlands in Ethiopia. There are four lakes found in CGRV, such as Dambal/Ziway, Langanno, Abijata, and Shalla lakes. Abijata and Shalla are saline with a pH of 9.3-9.5 and 9.0 -10, respectively, while Langanno and Dambal/Ziway are relatively fresh water [13, 12]. The central Rift Valley is the environmentally vulnerable areas in Ethiopia. Lake Abijata is one of the most important saline rift terminal lakes, which has different uses and ecosystem values. One important ecological value of saline and salt lakes is their role as feeding, refuge, and breeding sites for many water and water-related bird species. The East African saline lakes support spectacular concentrations of wetland-dependent wildlife, especially birds; 452 terrestrial and aquatic species of birds have been described from Lakes Shalla and Abijata, of which one is endemic [9]. Due to the presence of various bird species, the lake and its environs have been designated as one of the national parks (Abijata Shalla Lakes National Park).

Water is crucial for humankind, not only as a means to sustain our life, but as a determining factor in many production activities and conservation. These uses and values are increasingly subjected to degradation from a variety of different anthropogenic and climatic impacts like mining of soda ash, poor land use management, and over-pumping of water both on recharging feeder Rivers and directly from the lake

without accounting for environmental flows to downstream users and ecosystem services. Due to the high level of stress human development is putting on the environment and the services it provides, the concept of environment water use has arisen. Then, the park has already been converted in to farm and grazing land with many settlement areas which aggravate the stresses and impacts upon the lake.

Recently, Lake Abijata is the most endangered lakes of Ethiopia, next to Haromaya [5, 7]. Therefore, need to understand how water interacts with the environment and human activities order to properly determine how to protect humankind from potentially devastating effects of mismanaging, to optimize the benefits that it can bring to development with exemplary conservation. On the other hand, the most appropriate geographical entity for the planning and managing of water resources is the river basin, including surface and ground water.

There has been a clear decrease in water resources. Lake levels have been lowered, and wetlands have deteriorated. The shrinking of Lake Abijata has been a burning issue for many years, both by the local community, Abijata Shalla Lakes National Park, and different administrative bodies in the region and at the national level.

Therefore, this survey is based on the river basin scale. The river basin can be defined as the portion of land drained by a river and its tributaries, which may drain into Lake Abijata. In order to devise a water budget for this lake, knowledge of the water balance is required. Though, the detailed survey has been done with exhaustive literature review, field observation, and public and focal group discussions to provide baseline information on interference measures to decision makers for feasible management interventions to save this nationally and globally important rift lake.

Scope and limitations of the survey

In many ways, the existence of Lake Abijata depends on its upstream water catchments, so the survey covers the Dambal/Ziway Abijata catchment of the Dambal/Ziway Shalla sub-basin, but is limited to Lake Langanno watershed impacts like irrigation, industrial expansion, and Water supply. The direct and indirect effect of the Abijata Shalla Soda Ash Share Company on the environment and upstream water users that affect the flow of Bulbula and Horakello rivers are also main parts of the assessment. Then, the survey was mainly focused on reduction of the quantity of the lake water while hydro chemical changes are not addressed well.

MATERIAL AND METHODS

The study area description

The Central Rift Valley of Ethiopia is found between 38°15'E and 39°25'E, and 7°10'N to 8°30'N approximately, and 150 km away from Addis Ababa in a southern direction. The survey area is situated in two administrative regions (Oromia and the Southern Nations Nationalities, and Peoples Region) (Figure 1).

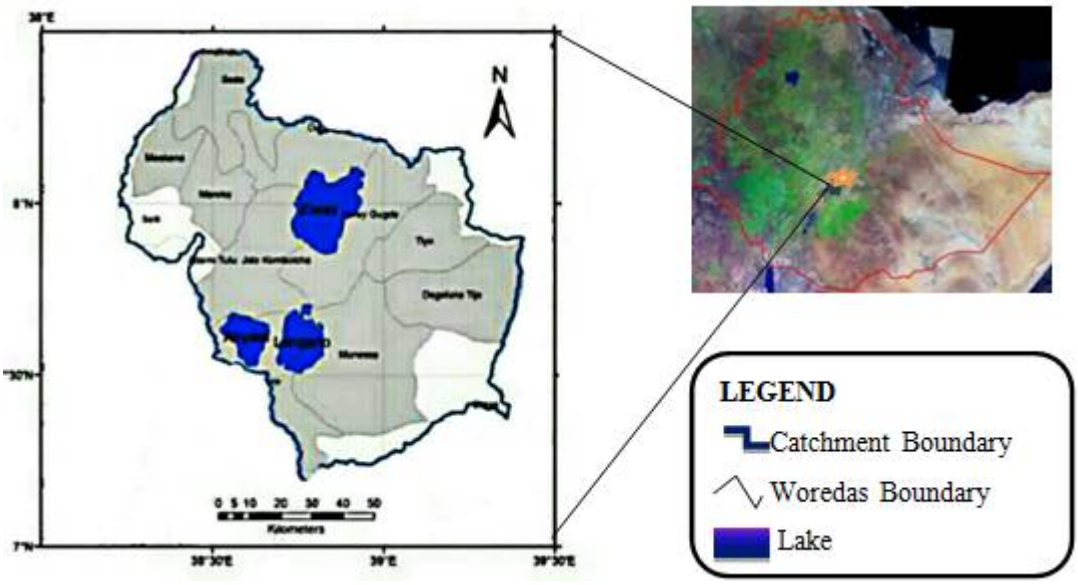

Figure 1. Map of survey area and location.

The Central Rift Valley is bounded to the west (Guraghie highland) and east (Arsi Mountain) with altitudes of more than 3000 m.a.s.l and a peak of 4245 m.a.s.l (Mountain Kaka, east of the lakes). The survey area can be delineated by the hydrological boundaries/watershed (the blue line in Figure 1) or the boundaries of the major woredas (used for the regional statistical information). There are ten woredas in survey

watershed area and within the two regional states (Table 1).

Table 1.Woredas found in the Dambal/Ziway-Abijata catchment.

Region	Woredas	Area (Km^3)
SNNPR	Sodo	830.17
	Meskana	366.15
	Mareko	504.22
Oromia	Dugda Bora	1514.23
	Adami Tulu JidoKombolcha	1250.49
	Tiyo	633.36
	Digeluf Tijo	972.33
	Zuway Dugda	1267.29
	Munessa	1520.61
	Negele Arsi	1,340.00
Total		10198.85

Catchment, sub-catchments and surface water

The survey area contains three large lakes, Dambal/Ziway, Langano, and Abijata (Figure 2). Lake Abijata, is a closed (terminal) lake without a surface water outlet (Figures 2 and 3). Lake Shalla is situated in an adjacent catchment; however, it is part of the Abijata Shalla Lakes National Park. The national park consists of the two saline lakes, Lake Abijata and Lake Shalla, and the surrounding woodlands. The Ethiopian Government has submitted the lakes to the Ramsar Convention on wetlands to be recognized as an international Ramsar site, but has not yet been recognized.

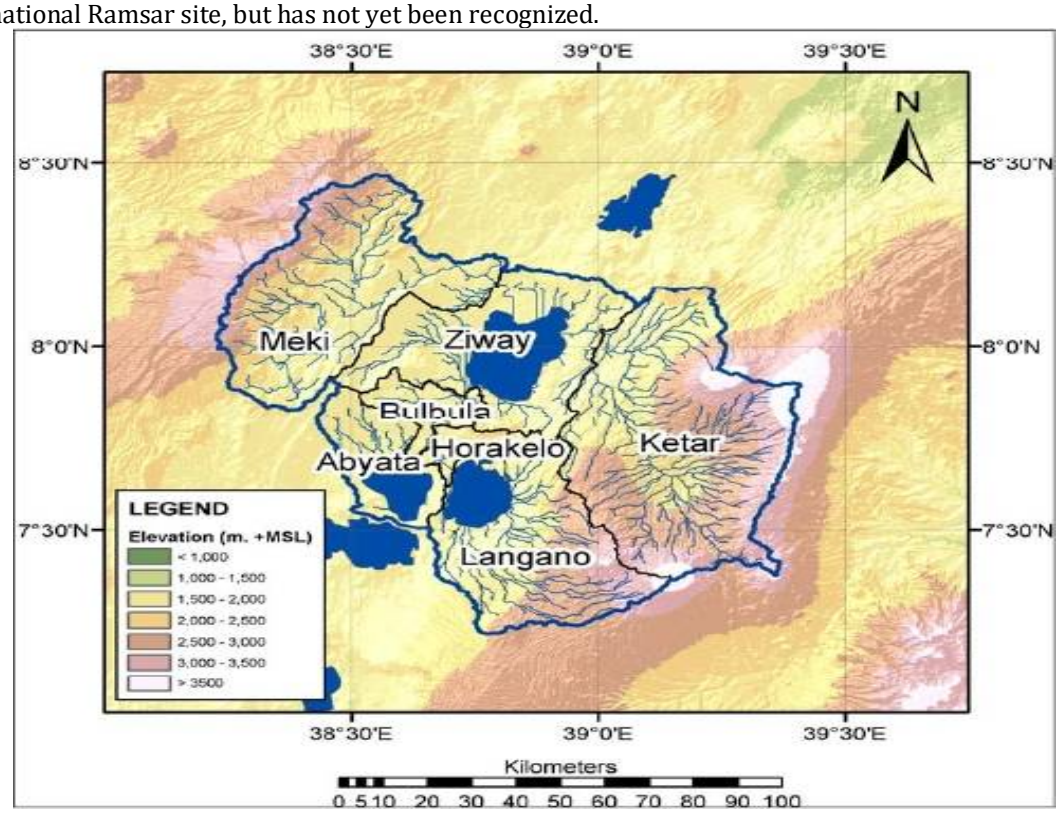

Figure 2. The catchment and sub catchment of the survey area delineation.

All the rivers and lakes in the study area are situated at an altitude above 1500 m.a.s.l.

Lake Dambal/Ziway is one of the largest freshwater Rift Valley Lakes of the country, and a, large, open, and shallow lake characteristics with a wide catchment. It has an average altitude of 1850 m.a.s.l, a surface area of 434 km^2, and an average depth of 4 meters, depending on water inflow. This lake is known mainly for its large size, fisheries, and islands [6]. The Maki and Katar rivers feed the lake from the north and northeast,

respectively. It is drained by the Bulbula River, forming unique and vital fresh water resources in the central Rift Valley Lakes system in the Southern part of Ethiopia. Besides the thriving fisheries, the lake supplies water for the town and irrigation for nearby floriculture farms.

Lake Langanno's high percentage of water comes from precipitation and twelve rivers that form the upper catchment (Figure 3). Hora kallo forms its only outlet flowing into Lake Abijata.

Lake Abijata is the terminal saline lake, being fed by rivers Bulbula and Horakelo, which are outflows from Dambal/Ziway and Langanno Lakes, respectively (Figure 3). Lake Abijata is a saline lake where water outflows only through evaporation naturally [21]. Therefore, the salinity is high. The Abijata Soda Ash factory was established to abstract soda ash and associated salts [17]. It was extracting soda ash since the late 1980s at a pilot scale.

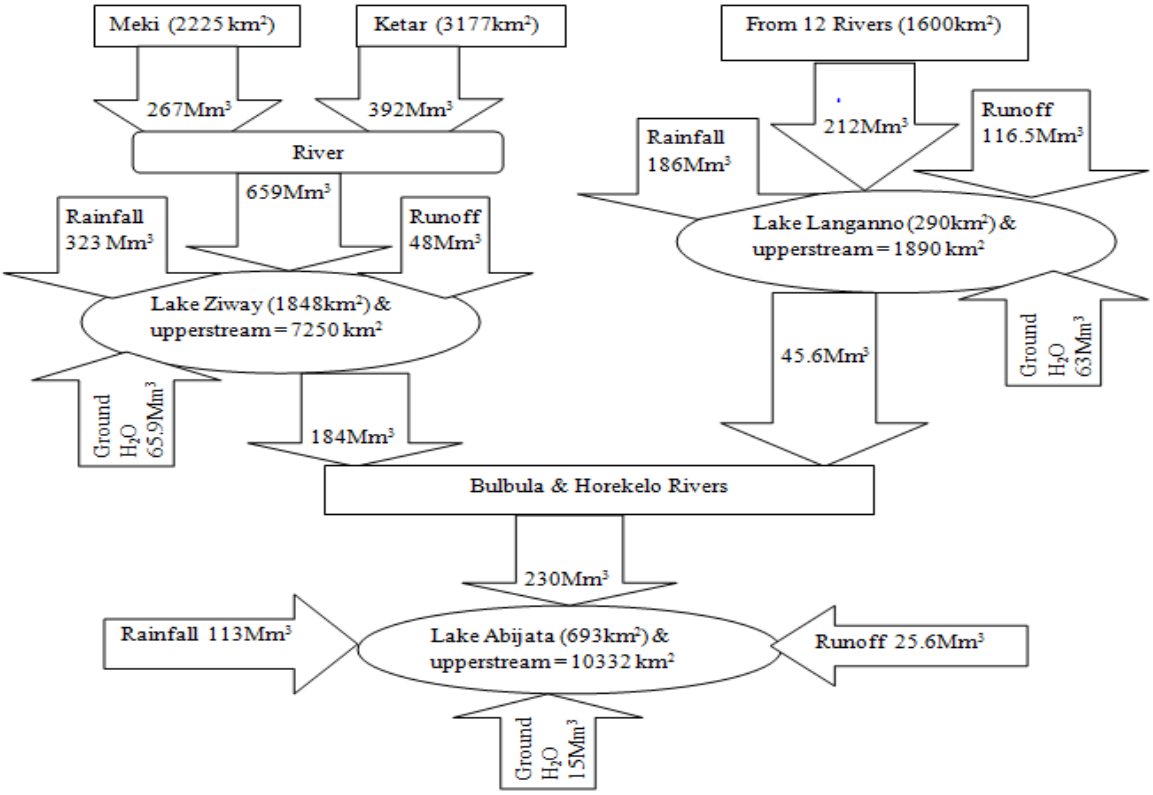

Figure 3. Lake Abijata's total catchment area, with the volume of water naturally river flows

The total surface area of the Lake Abijata catchment is approximately 10332 km^2 and consists of seven sub-catchments (Figure 2). The catchments of Lake Dambal/Ziway include the area around Lake Ziway, which directly drains to Lake Dambal/Ziway, and the catchments of the Meki and Katar rivers, which represent 74.5% of the total catchment. In the same way, the catchment of the Bulbula River adds in the area that directly drains to the Bulbula River, plus the entire catchment of Lake Dambal/Ziway. The Horakelo catchments also add in the entire catchment of Lake Langanno. Finally, the catchment of Lake Abijata includes the area that directly drains to the lake plus the entire catchment of the Bulbula and Hora kallo Rivers. Lake Abijata is the terminal lake [1, 4, 6].

Climate

The lakes of the Ethiopian Rift experience a wide range of climate, accentuated by the annual north-south movements of inter- and sub-tropical frontal zones across the country. The climate is humid to sub-humid in the highlands and semi-arid in the rift valley. The mean annual temperature is around 15 °C in the highlands and 20 °C in the rift valley. The average annual rainfall ranges from 650 mm in the rift floor and 1150 mm in the highlands [11]. The area has a bimodal rainfall pattern, with the main rainy season (June–September), locally known as Kiremt, and a short rainy season (March–April), locally known as Belg, as well as the dry season, which lasts from October to February.

Biodiversity

The four central rift valley lakes, including Abijata, are globally important natural resources that provide many ecosystem services and host Ethiopia's rich biodiversity resources. Great White Pelicans, Flamingos, Ostriches, Ducks, and many other birds are among the avifauna [17, 20, 2, 3, 4]. Abijata was once named

bird watchers' paradise and a well-known site to see thousands of Lesser Flamingo populations in Africa [18], which is significantly reduced in number now a days [3].
The Mammal species in the area include Grant's Gazelle, Jackals, Oribi, Warthog, bushbuck, Hyena, Rabbit, Monkey, and others [20].
The vegetation around the lakes is a tropical savannah dominated by acacia species, Balanties, shrubs, and bushes. Acacia trees are dominant and an important means of income (charcoal) for the local people [18].
Lake Abijata is rich in phytoplankton. A dominant population of *Spirulina* species was reported from Lake Abijata in the 1960s [19]. But later it was found to be sub-dominant with frequent blooms of a nitrogen-fixing cyanobacterium *Anabaenopsis abijatae* and zooplanktons that exist in Abijata Lake, where the Great White Pelicans depend on for feeding [18].

Methodology of the survey

Structured questionnaires were prepared to collect hydrology data, land use, water quantity, water use, and environmental rehabilitation and management. Interviews and extensive discussions were made with respective stakeholders. On the discussion different actors and stakeholders, were identified in the district. Finally secondary data literatures were compiled exhaustively reviewed and analyzed.

RESULTS AND DISCUSSION

Threats

The main threats that could negatively affect the lake include overgrazing, deforestation of the upper catchment of the lake, abstraction of the lake water for soda ash mining, and upstream water abstraction, especially from Bulbula River. The lake may dry up at the end due to the fall of its water table.
The population of the sub-basin is increasing from time to time due to the development of irrigation agriculture, industrialization, and urbanization, which attracts migrants from different parts of the country. These conditions made the area overpopulated and created pressure on natural resources such as water and biodiversity. The vast plains around Lake Abijata are being used for grazing. Many thousands of livestock rely on the grass grown around the lake. The population density is high in the area. The population pressure has grown dramatically in the area. As a result, the forested woodland has become sand blown area due to extensive farming and deforestation for charcoal production. The Abijata Shalla Lakes National Park is now converted into a settlement area with many farm plots.
Agriculture is the mainstay of the local community, encompassing crop and vegetable production, livestock rearing, fishing, and income from off-farm activities. The explanation of irrigation agriculture, industry, and urbanization affects the local community's livelihood both positively and negatively.

Soda Ash production and processing

The purpose of establishing the Plant was to produce soda ash for the caustic soda factory in Batu town and for export. The product Trona is a naturally occurring mineral-Sodium Sesqui carbonate: $NaHCO_3 \cdot Na_2CO_3 \cdot 2(H_2O)$ [10]. It is primarily used to make soda ash (Na_2CO_3) by calcining or heating the Trona at very high temperatures (650-750°C) and converting it to sodium carbonate [13].
For the production, the plant is entirely dependent on Lake Abijata for water, which has contributed to a reduction in the lake level and an increase salt concentration. Changes in lake level affect its salinity, with data showing an "increase of 260% in the salinity level over the two years 1986-1988" [15].
In addition, the Pilate taste, the Plant extracts about 5,000,000 m^3 of water from the lake, which represents approximately 1% of the total water lost from the lake naturally [15]. However, when the factory started full Trona production, it used a large amount of water, about 30,000,000 m^3 per annum. from the lake to artificial pond where the water is dried through artificial evaporation.
Table 2 provides detail on changes in Lake Abijata water levels and area in response to Soda Ash production.

Table 2. Lake Abijata long term average response for soda ash production

Scenario No.	Soda ash production (tones/year)	Change in lakes level (m)	Change in mean lake area (%)
1	4,500	0.03	-
2	10,000	0.04	0.50
3	20,000	0.14	1.90
4	1,000,000	7.62	89.00

Source: RVLB Master Plan [16]

The plant extracts mineral resources from the lakeshore and also disposes of residue and waste on the lakeside. The waste is drained into the lake during the rainy season, which could, in turn, affect the fish

population that birds depend on. Currently, no fish-eating birds are observed at the lakeshore compared to the population from about 25 years ago (Personal observation).
Due to the rapid decline of the lake, the factory has stopped pumping water. It is also indicated that they will shift this practice to Lake Shalla. The cessation of production is entirely related to technical reasons (difficulty in pumping as the lake recedes). What effect this will have on Lake Shalla remains to be seen. It is likely that the same environmental problem will arise unless a proper environmental management plan is implemented.

Irrigation and water demand

Domestic water demand includes drinking, washing, bathing, cooking and other household uses. According to the RVLB Master Plan [16], in the Dambal/Ziway Shalla sub-basin, there are a total of 49,250 ha of planned irrigation, but the analysis estimates that only 8,588 ha could be supported (Table 2). The domestic demand is calculated by assuming the average national water use rate.
Jensen *et al.* [10] calculated domestic demand in the sub-basin by assuming the average national water use rate. This highlights the urgency for integrated management of basin-wide water and land resources.

Table 3. Water use upstream in the Abijata watershed catchments (from seven sub catchment).

Demand site	Total Area (ha)	Required Water Allocation m^3/ha or m^3/person)	Water consumption m^3 per year
Meki Irrigation	388.00	12,087.00	4,689,756.00
Katar Irrigation	856.00	11,483.00	9,829,448.00
Dambal/Ziway Irrigation	2,000.00	12,691.00	25,382,000.00
SherEthiopia	500.00	14,600.00	7,300,000.00
Castel Wonery	500.00	2,200.00	1,100,000.00
Bulbula Irrigation (farmers)	477.00	12,691.00	6,053,607.00
Bulbula Irrigation (investors)	3,037.00	12,691.00	38,542,567.00
Langanno Irrigation	830.00	12,691.00	10,533,530.00
Soda Ash	15,800 ton	150 m^3/ton	2,370,000.00
Dambal/Ziway Water Supply	43,660 (person)	32.80	1,432,048.00
Bulbula Water Supply	5,000 (person)	32.80	164,000.00
Total	**8588**		**107,396,956.00**

As shown in Table 3, the water demand by the local community and investors for different purposes indicates 107.4 million m^3. As a result, there is a visible change in almost all lakes, primarily due to water usage from lakes and Feeder Rivers.
Furthermore, there are plans for increased irrigation in the basin [16]. Planned development activities in the Dambal/Ziway-Shalla sub-basin include the expansion of Abijata Shalla Soda Ash S. C., Castel Winery Plc., Sher Ethiopia plc., Frigofrico Boran Plc., Alfoz Quarantine Plc., Elfora Agro industry, and Verde Cattle fattening Plc., to name a few. The estimated annual gross water demand totals 701.81-million-meter cube. Abijata Shalla Soda Ash S.C, Sher-Ethiopia Plc., Frigofrico Boran Plc., and irrigation represent the majority of water consumption. Industries, mostly agro-industry, will extract large amounts in the future. The ecosystem is clearly stressed; future development and water resources remain imbalanced.

Water balance of catchment area and river flow

The precipitation pattern in the rift floor is more stormy compared to the highlands [11]. The main rainy season lasts from June to September.
In an equilibrium situation, the inflow into the lake from the Bulbula River, the Hora kallo River, direct runoff from the surrounding area, and groundwater inflow should equal the lake's evaporation minus rainfall on the lake approximately [8]. This is because the evaporation of water is directly proportional to the lake's area coverage. In other words, the inflow of water into the lake is directly proportional to the increase in the lake's area coverage. Therefore, the increase in evaporation depends on the increase in the surface area of the lakes.
According to Kassie *et al*. [11] during the period 1977-2007, total mean rainfall decreased but was not significant. Additionally, there was a decrease in the number of rainy days, which was associated with an increase in the intensity of each rainfall event during the main rainy season. This could have implications for soil and nutrient losses due to erosion and runoff. This means that if the intensity of rainfall increases; surface runoff should also increase, resulting in rivers feeding more water into the lakes annually. Thus, the rise of lake levels presents an opportunity if the upper water users adopt efficient water consumption

strategies. Although climate change is not significant compared to anthropogenic factors in reducing the size of Rift Valley lakes [6].

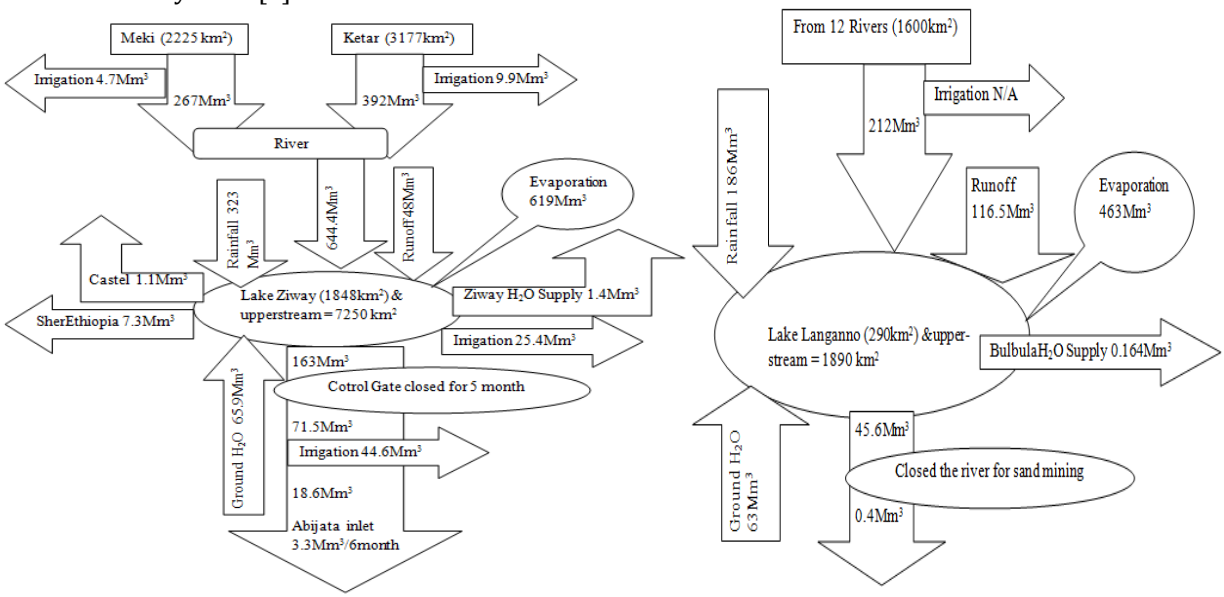

Figure 4. The water balance of Lake Dambal/Ziway is discharged through Bulbula and Langanno, which flow into the Horekelo rivers, ultimately reaching Abijata Lake
(Source: [21, 4, 5, 11]; personal observation)

The discharge of major rivers that feed rift lakes is governed by the climatic and hydrological regimes of the adjacent highlands. The flow regime of the rivers in the rift is more influenced by water diversion and the closure of the outlet by the control gate than by climate change (Figure 4). At the outlet of Lake Ziway, the average discharge was 5.24 m^3/sec; after a distance of 1.6 kilometers from the outlet, it reduces to 2.3 m^3/sec at the regulator. At the bridge in Bulbula town, it is 0.599 m^3/sec; at the site between Bulbula town and Lake Abijata in Desta Abijata kebele, it is 0.232 m^3/sec, and at the inlet to Lake Abijata, the flow diminishes to 0.21 m^3/sec (RVLBA documentation, 2016). As a result, the Bulbula River produces only 3,265,920 m^3 of water for Lake Abijata within six months. The main feeder river, Bulbula, progressively decreases in flow until it joins Lake Abijata from the outlet of Ziway. Downstream local community water users are at the mercy of those who control the gate and the significant water users around Lake Ziway. All downstream water users are complaining about the water quantity and quality in the area. Therefore, the change in the size of Lake Abijata is directly influenced by the pumping of lake water and the river Bulbula for different water uses.

Lake level change

Lakes Dambal/Ziway, Langano, and Abijata are hydraulically connected and inseparable through groundwater and surface water [13, 14, 16].

The most dramatic effect of water use for industry and agriculture in the Langano and Dambal/Ziway watershed goes directly to Lake Abijata as it is a terminal lake. Any water use upstream in the Dambal/Ziway and Langano catchments dramatically affects the water balance of the terminal Lake Abijata (Figure 4). Lake Abijata as shown in the map below (which accounts water use and hydrological balance), indicates that Lake Abijata is in real danger of disappearance maybe in few years (Figure 5).

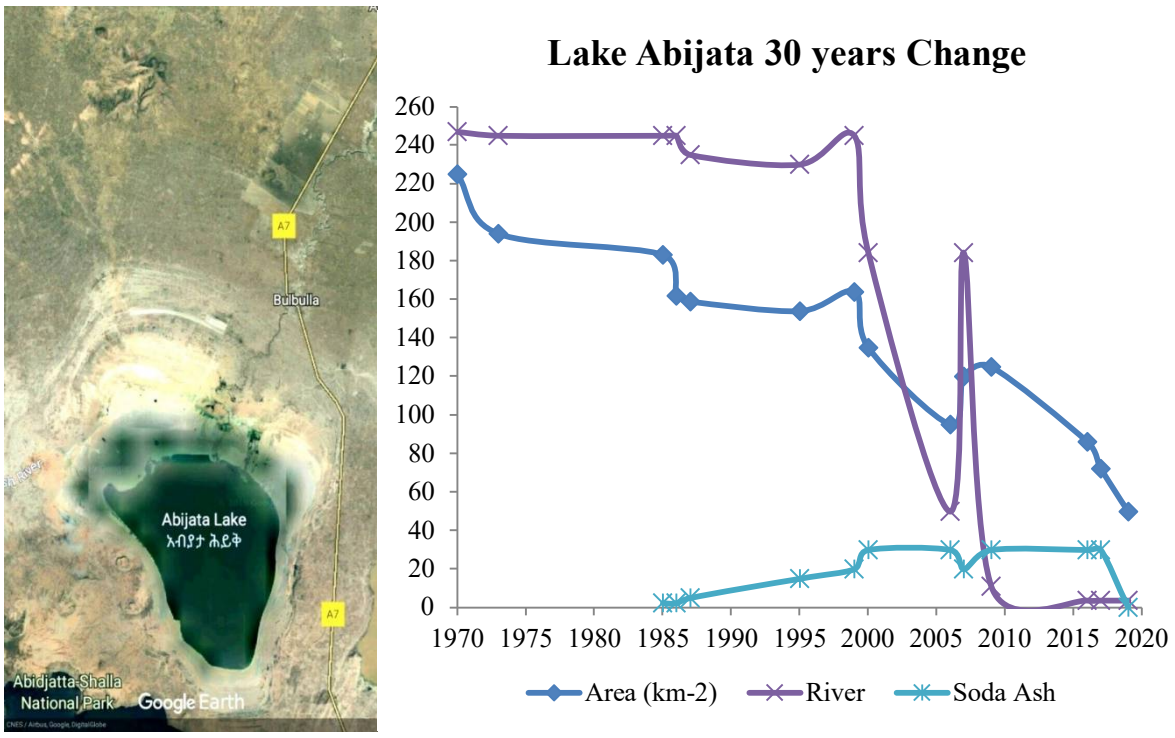

Figure 5. Map showing Shrinking Lake Abijata, derived from Land Satellite Normalized

The dramatic decline in the level and size of Lake Abijata is related to the decreased flow of the Bulbula River (which accounts for over 75 percent of the water in Abijata), the reduced flow of water from Lake Dambal/Ziway, and the direct pumping of water for soda ash production (Figure 4, Table 3).

The lack of flow in the Horakelo River has also changed Langanno into a terminal lake. This is an absolutely alarming situation for all three important lakes. It is likely that the relatively fresh lakes of Dambal/Ziway and Langanno could be transformed into saline lakes unless they remain open with proper water management interventions.

A serious threat is that the control gate turns Lake Dambal/Ziway into a terminal lake. This will cause that Lake Dambal/Ziway to eventually become saline, similar to lake Lake Abijata. Additionally, Lake Dambal/Ziway has been converted into a terminal lake by the control gate, where only a small amount of water is released to downstream users. The operational rules of the gate and their proper implementation are the most critical issues for the survival of Lake Abijata and the community living downstream around the Bulbula River.

The impacts of over water use on local community

Thousands of domestic animals such as cattle, camels, shoats, and equines depend on the wetlands surrounding Lake Abijata, Lake Dambal/Ziway, and the Bulbula River during both the rainy and dry seasons. The farming communities around Lake Abijata are severely affected as the volume of the Bulbula and Horakelo Rivers is decreasing over time; specifically, the past ten years have shown the lowest volumes, resulting in dry conditions during much of both the wet and dry seasons. The current practice of abstracting water for irrigation and soda ash production competes with both domestic needs and the ecosystem's use of water. The stress on domestic water demand along the Bulbula River has already caused conflicts over water resources among individuals, communities, and investors. Consequently, there is a lack of trust in the government and a developed negative attitude towards investments due to the illness and death of cattle caused by water shortages and pollution. Additionally, the migration and resettlement of farming communities and cattle near Dambal/Ziway Lake could impact the lake's ecosystem, which is the only freshwater lake in the basin.

Irrigation on the Bulbula River has become difficult, creating water use conflicts among communities living in the upstream and downstream areas. The bare land created due to the drying of the Bulbula River and Lake Abijata serves as a source of soil dust and wind erosion, thereby affecting crop production and causing local human and animal health problems.

The impacts of over water use on biodiversity

The chemical concentration of the lake is dramatically increasing, and salinity has been changed over the years; the Soda Ash S.C. plant has strongly impacted the structure and function of various biological

communities of the Lake Abijata [1]. Studies show that the increase in chloride and salinity levels will diminish species diversity. Therefore, salt-tolerant species may increase, and halophobic species may decrease, resulting in biodiversity loss, such as spirulina algae and well-known fish.
Generally, due to land use and cover change, human and livestock population pressure, water scarcity, and climate variability, many species of plants and wildlife are under threat. It is also difficult to observe the rich avifauna currently.

CONCLUSION

The basin contains nested lakes influenced by rainfall and volcanic terrain, yet faces rapid land degradation. Major nested Lake Abijata shows significant biophysical and chemical changes, with water levels shrinking due to human activities and climatic factors. Outflow from Langanno through the Horakello River has ceased, and flow from Lake Ziway is now seasonal due to a control gate. As a result, Lakes Langanno and Ziway are becoming terminal lakes. Soda ash production further affects Lake Abijata, which has seen dramatic land-use changes as farmland overtakes the area, leaving only remnant trees in the national park, while the dried lakebed is used for grazing. Once valued for ecotourism, is diminishing due to poor park management. In the Ziway-Shalla sub-basin, competition for water among large users often disadvantages downstream users and degrades ecosystem services, calling for urgent change. Future plans to utilize sub-basin water lack proper resource assessments, underscoring the need for a detailed study before issuing usage licenses. Water use is often inefficient, highlighting the necessity for improved efficiency and fair distribution among consumers, considering local communities. The Abijata Soda Ash Company is struggling and plans to shift to Lake Shalla, which requires an ESIA study. The current factory intends to halt operations, as continued extraction is unsustainable. Vulnerable water resources necessitate promoting efficient and equitable use for sustainable development. The Ethiopian Environmental Protection Policy emphasizes environmental concerns and local livelihoods for sustainable development, but many activities overlook these issues. The crisis facing Lake Abijata stems from poor water management, necessitating a stakeholder plan to promote sustainable resource practices and build investor confidence.

RECOMMENDATION

To preserve and protect this endangered Lake Abijata and its surroundings, the following short, medium and long-term efforts are needed.

Immediate interferences:

- The operational rule for the control gate of Lake Ziway outlet must be established and made transparent to all water users. In any operational guidelines, the Bulbula River should be permitted to flow through its channel for ecological sustainability, domestic use, and livestock.
- Pumping water from the lake using a floating pump should be avoided, because such system can pump the lake dry. Additionally, implementing a water tariff is also difficult with this system (Sher-Ethiopia).
- Quantify accurately the amount of water being abstracted from the basin by conducting a detailed water balance analysis and establishing a system to control the volume of water to be abstracted.
- Implementing the above recommendation alone is insufficient for using this river water for domestic purposes; immediate measures must also be taken to prevent water pollution, such as stopping the Sher-Ethiopia Flower Farm from contaminating the water or Lake Dambal/Ziway.
- The Abijat Shalla Soda Ash Factory has already stopped pumping due to the reduction of Lake Abijata, but it has a future development plan to expand to Lake Shalla. Considering the livelihood restoration of the factory's employees, this investment should be redirected toward more environmentally friendly initiatives such as ecotourism in this fragile environment.
- Further consultation and raising awareness are important to prevent water use conflicts and misunderstandings regarding environmental changes in the area.

Middle term interferences:

- Promote the use of efficient technology and create incentive mechanisms for it. This may include establishing water recycling and changing the irrigation system, such as switching from furrow/flood to drip. It might also be beneficial to conduct a study on crop water requirements. If there is visible stress on the lakes, they should cultivate only plants that require less water.
- Large water users must employ efficient technology and irrigation systems, such as those used by the Castel winery. Creating incentive mechanisms is important for such interventions.
- To use water resources sustainably, priority should be given to equitable allocation of water for all users. In doing so, the conservation and protection of the ecosystem and the livelihoods of the rural community should not be compromised. To minimize and ultimately avoid the social and environmental problems related to water use conflicts and competition, an urgent call must be made

to all stakeholders, and appropriate national implementing body must be established before it is too late.

- As stated on water policy, the "polluter's pay" principle must be implemented. This requires continuous monitoring of water quality and mapping of point and non-point sources of pollution. Any polluter must be held liable for the damage.
- Quantify how much water is being extracted from the basin by various water users and assess the available resources based on scientific data. Hydrology is highly dynamic. Previous work on water balance cannot be applied to current conditions. This necessitates the involvement of research institutes in this effort, including the development of operational rules for the control gate at the outlet of Lake Dambal/Ziway.
- The shoreline vegetation, which supports numerous bird species as well as water-dependent aquatic fauna and flora, should be conserved and protected by establishing an integrated and sustainable system for managing aquatic and terrestrial resources. As the first step, an urgent plan must be developed to delineate a protected shoreline (buffer zone) to prevent any encroachment.
- Basin-wide integrated and participatory watershed management should be planned and implemented.

Long term interference:

- Review and evaluate the current and long-term monitoring programs, and develop guidance for incorporating considerations of biodiversity loss impacts into the monitoring design.
- Lake Abijata and its surroundings have great potential for ecotourism and biodiversity conservation. Therefore, relevant government organizations and non-governmental organizations should prioritize this and the sustainable use of natural resources for generations.
- Abijata Shalla Lakes National Park should be free from farming and grazing practices. Of course, this requires workable resettlement and community development plan that involves the engagement of various stakeholders at different administrative levels.
- Clearly, the water demand will increase significantly in the area due to growing irrigation, industrialization, and urbanization. This necessitates a proper, detailed feasibility study and a strategic development plan that address the short, medium, and long-term water demand. The licensing of industrial and agricultural zones must be align with the strategic plan.
- Enhancing the community's climate resilience through various climate change adaptation and mitigation measures.
- Integrated and participatory watershed management on a basin-wide scale should be planned and implemented over the long term.

Overall, it is essential to engage academia in the problem-solving research involved in the mitigation measures discussed above. Without research, the sustainability of these measures will be uncertain.

Effective stakeholder engagement enables the relevant bodies, including sub-basin water users, to participate intensively in the planning, decision-making, and evaluation of all activities related to the preparation and implementation of the Lake Watershed management plan. To develop realistic and applicable engagement plans, stakeholders must first be categorized to facilitate the consultation, data collection process, and final implementation. The engagement stages should be defined to outline the steps or phases in which stakeholders will participate. Without a proper stakeholder engagement plan, interventions may not be effective.

AUTHORS CONTRIBUTIONS

Lalisa Mekonnen Jaldu: Conceptualization (lead); data collection and curation (lead); formal analysis (lead); investigation (lead); methodology (lead); project administration (lead); validation (lead); writing original draft (lead); writing review and editing of the writing (lead). **Hailu Tilahun Argaw**: Conceptualization (lead); data collection and curation (lead); formal analysis (lead); investigation (equal); methodology (lead); project administration (equal); validation (equal); writing original draft (equal); writing review and editing of the writing (equal).

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

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