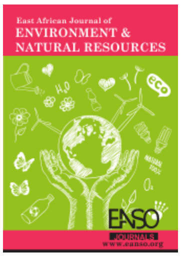

East African Journal of Environment and Natural Resources
eajenr.eanso.org
Volume 6, Issue 1, 2023
Print ISSN: 2707-4234 | Online ISSN: 2707-4242
Title DOI: https://doi.org/10.37284/2707-4242

EAST AFRICAN NATURE & SCIENCE ORGANIZATION

Original Article

Water Security Problems of Lake Tana and Its Possible Management Options: A Review

Abebe Tesfaye[1*]

[1] Ethiopian Forestry Development, P. O. Box 2128, Bahir Dar, Ethiopia.
[*] Correspondence ORCID: https://orcid.org/0000-0001-9178-4135; Email: abebetesfaye07@gmail.com

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

Date Published:

16 December 2023

Keywords:

Water Level, Water Quality, Pollution, Water Hyacinth, Sedimentation, Trophic Status, Lake Tana

ABSTRACT

Lake Tana is the largest lake in Ethiopia and accounts for 50% of the country's freshwater resources. It provides a unique habitat for biodiversity and plays an economic role via tourism, electricity, agriculture, fishery, and, most importantly, it provides drinking water to the local inhabitants. Because of its immense water resource potential for socioeconomic development, Lake Tana has been identified as a major economic corridor in the country. Given the importance of the lake to the region and nation's economy, human health, and livelihoods, assessing the water security problems of the lake in terms of water scarcity and quality is critical for its sustainable management. Doing so, studies on water level fluctuation and water scarcity, and physicochemical and related hydrological and biological features of the lake, which have been reported in the literature over more than a decade, were reviewed, and the studies showed that water level fluctuation was observed and resulted in water scarcity problems for surrounding communities. In addition to water scarcity and water fluctuation problems, the lake's trophic status has also gradually changed from oligotrophic to mesotrophic and eutrophic. In addition, faecal pollution, heavy metal pollution, and toxicogenic cyanobacteria are detected in the lake, especially on the shores and its tributary river mouths. Moreover, Lake Tana is infested by the ecologically dangerous and worst invasive weed, the so-called water hyacinth, with rapid area coverage and has resulted in dominant other important floras and posing a significant negative impact on water quality, biodiversity, fishing, water supply, water transportation, and other economic activities. There are options recommended to manage the lake. In this regard, different lake ecosystem management options like delineation of buffer zones, integrated watershed management, awareness creation about the lake and its associated wetlands, development of waste management practices, eradicating/reducing water hyacinth, and enforcement of environmental related policies and Strategies are recommended for sustainable management of Lake Tana.

APA CITATION

Tesfaye, A. (2023). Water Security Problems of Lake Tana and Its Possible Management Options: A Review. *East African Journal of Environment and Natural Resources*, *6*(1), 473-490. https://doi.org/10.37284/eajenr.6.1.1631.

CHICAGO CITATION

Tesfaye, Abebe. 2023. "Water Security Problems of Lake Tana and Its Possible Management Options: A Review". *East African Journal of Environment and Natural Resources* 6 (1), 473-490. https://doi.org/10.37284/eajenr.6.1.1631.

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

HARVARD CITATION

Tesfaye, A. (2023) "Water Security Problems of Lake Tana and Its Possible Management Options: A Review", *East African Journal of Environment and Natural Resources*, 6 (1), pp. 473-490. doi: 10.37284/eajenr.6.1.1631.

IEEE CITATION

A. Tesfaye. "Water Security Problems of Lake Tana and Its Possible Management Options: A Review", *EAJENR*, vol. 6, no. 1, pp. 473-490, Dec. 2023.

MLA CITATION

Tesfaye, Abebe. "Water Security Problems of Lake Tana and Its Possible Management Options: A Review". *East African Journal of Environment and Natural Resources*, Vol. 6, no. 1, Dec 2023, pp. 473-490, doi:10.37284/eajenr.6.1.1631.

INTRODUCTION

Lake Tana is the largest Lake in Ethiopia which accounts for 50% of the freshwater resource of the country, and it is the source of the Blue Nile, supporting the lives of over 123 million people in the Nile Basin by its 60% approximate contribution to the basin (Goshu & Aynalem, 2017). It has been used for various developmental activities, including fisheries, irrigated agriculture (commercial farming), transportation, livestock watering, and hydropower generation (Anteneh et al., 2015). Most importantly, it provides drinking water to the local inhabitants and serves as cleaning and laundry.

The lake is a unique ecosystem with diverse flora and fauna, making it an important biodiversity hotspot. It has been listed in the top 250 lake regions of Global Importance for Biodiversity (Dersseh et al., 2020). It has 28 species of fish, of which 21 are endemic, including the only remaining flock of endemic Labeobarbus fish in the world. It is used for fishing and farming and has a thriving tourist industry centred on the more than 30 islands on the lake. In recognition of the lake's rich biodiversity and significant cultural heritage, UNESCO added the lake to its World Network of Biosphere Reserves in June 2015. However, the water resources of Lake Tana are not utilized sustainably for the socioeconomic development of the region in particular and the country in general. The development intervention outweighs the environmental protection and management, which leads to resource degradation (Teshale et al., 2002). As a result, Lake Tana is facing several water security problems affecting its ecosystem's sustainability and the livelihoods of the people who depend on it.

Water security problems of Lake Tana, comprising water scarcity and water quality problems, arise from various factors, including climate change, high population growth, water abstraction, pollution, and habitat degradation. Unregulated increased water abstraction from the lake for irrigation and domestic use has reduced water levels (Wubneh et al., 2022) and decreased water quality (Teferi et al., 2021). Furthermore, the discharge of untreated sewage, agricultural effluents, and industrial waste into the lake has also contributed to the deterioration of its water quality and the health of its aquatic ecosystem, making it unsafe for human consumption (Wondyfraw et al., 2019). The aggravation of the noxious weed, the so-called water hyacinth, is also one of the indicators for the water security problems of Lake Tana, posing a significant threat to livelihoods, biodiversity, climate, and tourism. Indeed, water security problems in Lake Tana are a crucial topic of study for managing water resources sustainably, protecting human health, preserving local economies, maintaining ecosystem balance, and understanding the impact of climate change.

Given the importance of Lake Tana to the region and the nation's primary source of water for ecological, economic, and social activities, including agriculture, hydropower generation, fisheries, and domestic use for millions of people in the upper Blue Nile Basin, assessing the water security problem of the lake in terms of scarcity and quality is very critical for its sustainable management. There are potential risks of water scarcity, declining crop yields, energy shortages, and conflict that could lead to significant economic, environmental, and social consequences for the region and beyond if the water security issues of the lake are not addressed.

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

To this end, this review summarizes different data and information related to water security problems to bring forward relevant development and policy intervention ideas for the sound management of Lake Tana and its associated resources.

Methodology

I inspected the water security problems of Lake Tana including origin of Lake Tana and its morphometric characteristics, water scarcity problems, water quality problems, and possible management options. A narrative synthesis method was adopted for this review. The review comprised both published and unpublished documents including articles, books, reports, and proceedings.

Findings and Discussion

Origin of Lake Tana and Its Morphometric Characteristics

The Lake Tana sub-basin in Ethiopia has a complex geological history shaped by volcanic activity and tectonic processes. The sub-basins geomorphological setting consists of lavas that erupted from shield volcanoes or fissures during the Tertiary and Quaternary eras. These lavas were later uplifted and eroded primarily by water (Ludwin et al., 2013; McCann & Blanc, 2016). Indeed, Lake Tana was formed by volcanic activity by blocking the Blue Nile flowing water by a lava barrier in the early Pleistocene 5 million years ago (Ludwin et al., 2013). In addition to the Blue Nile being blocked to the south by a lava barrier, epirogenetic subsidence also contributed to the formation of Lake Tana. The lava also separated the lake and its headwaters from the lower Blue Nile basin by 40 m high falls at Tissisat, 30 km downstream from the Blue Nile outflow (Vijverberg et al., 2009).

The centre of the Lake Tana basin is underlain by multi-layered volcanic formations covered with thick alluvial and residual Quaternary sediments, and the lake's basement comprises a mix of Pre-Cambrian, Metamorphic, and Granitic rocks (Goshu et al., 2017). Recent geophysical and core data show nearly 100 m of accumulated sediments in the lake’s bottom substrates (Lamb et al., 2007). In these sediments, desiccation layers indicate that the lake dried out at apparently regular intervals during the later stages of the last Ice Age 10,000–25,000 years ago. The data indicate that Lake Tana dried completely out between 18,700 and 16,700 calibrated age (cal) BP when stiff sediments at the base of the core were deposited (Vijverberg et al., 2009). The extensive deposits of Mesozoic sedimentary rocks that do not outcrop in the Tana basin but are observed in Abay Valley contribute to the basin's complex geologic history.

When Lake Tana reached its maximum extent, extensive lacustrine plains such as the Fogera and Dembia plains were created, and river valleys and basins were filled with sediment while higher-lying topography was eroded. Lake Tana plays a lesser role in the landscape formation because of its decreased extent compared to the ancient maximum at the current time relative to the past time (Ludwin et al. 2013). According to the same author, minor changes have been recorded on the lake's coastline, except for the delta formed by the Gilgel Abay River, which has increased disproportionally over the last 15 years. Poppe et al. (2013) reported that the lake plays a lesser role in landscape formation because of a decreased extent (3041 km2) compared to the ancient maximum (6514 km2). The bottom substrate of Lake Tana is mostly volcanic basalt covered with a muddy substratum that has little organic matter content, 1% in 1994 (Howell & Allan, 1994) and 14% in 2011 (Goshu, 2011). The lake has more than 40 tributary rivers, of which Gilgel Abay is from the south, Ribb and Gumara are from the east, and Megech River is from the north. These are major rivers feeding the lake. The only river flowing out of Lake Tana is the Abay River.

Morphometric characteristics of Lake Tana, the largest water body in Ethiopia, are indicated in Table 1. It is located in the Northwestern highlands of Ethiopia, and it geographically extends from 11˚ 0’ ‘to 12˚ 40’ 0’’ N latitude and from 36˚ 40’ 0’’ to 38˚ 20’ 0’’ E. longitude. It is a

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

shallow lake with a maximum and average depth of 14 m and 8 m, respectively (Ewnetu et al., 2013). The Lake Tana catchment area covers 16,111 km2 (*Table 1*). The distance from north to south is approximately 84 km, and from east to west, it is 66 km (*Table 1*).

Table 1: Morphometric characteristics of Lake Tana

Morphometric characteristics	Values	Sources
Latitude Longitude	11°36′ N, 37° 23′ E	Amare (2020)
Altitude (m)	1830	Vijverberg et al. (2009)
Maximum Lake length (km)	90	Goshu *et al*. (2017)
Maximum Lake width (km)	65	”
Lake area (km^2)	3111 km2	”
Maximum depth (m)	14	Sitotaw et al., 2022
Mean depth (m)	8	”
Lake volume (km^3)	284 km3	Seifu *et al*. (2005)
Water residence time (years)	3	”
Runoff coefficient (k)	0.22	”
Catchment area (km^2)	16,500 km2	Jacobus *et al*. (2009)

WATER SCARCITY AND WATER LEVEL FLUCTUATION PROBLEMS OF LAKE TANA

Water Scarcity Problems of Lake Tana

The water scarcity problem of Lake Tana refers to the imbalance between the water demand and supply in the lake basin, which has resulted in water shortages, environmental degradation, and social conflicts. The lake faces various water-related challenges, including increasing demand for water from population growth and economic development, inefficient water use practices, and the impacts of climate change. Communities living in the sub-basin have also raised concerns about potential water scarcity and the drying up of streams, which then causes water insecurity. The overuse of water resources, particularly for irrigation, has led to the depletion of groundwater reserves and reduced the water flow to downstream regions (Teferi et al., 2021). According to the same author, irrigation water withdrawals during the dry season cause water scarcity, conflicts, and environmental damage. For example, the eastern side of the sub-basin faces water shortages as the dry season flow is insufficient for irrigation, which is responsible for water shrinkage and scarcity problems. This results from various human activities and environmental factors such as the overuse of freshwater resources, inefficient irrigation practices, and the cultivation of water-intensive crops. The water scarcity problem in Lake Tana has also led to a decline in fish populations and decreased crop yields, affecting the livelihoods of many people in the region. The situation has also led to conflicts among water users who want to maximize their profit from the lake and its resources (Goshu & Aynalem, 2017).

The Causes of Water Scarcity in Lake Tana

Climate Change

The lake receives water from several rivers but has been experiencing reduced inflow due to drought and overuse because temperature and precipitation trend fluctuations influence the components of the hydrological cycle and the availability of water supplies and their resulting shifts in the balance of lake water level (Wubneh, 2022). According to the same author, climate change has caused changes in rainfall patterns, resulting in a decrease in precipitation in the watershed of Lake Tana. This has led to a reduced inflow of water into the lake, decreasing its water levels and water storage capacity.

Population Growth

The Lake Tana basin is a densely populated area. An estimated five million people live in the lake catchment due to the high population growth rate and immigration (Sewnet & Kameswara, 2011). This has resulted in a high population dependency on the lake’s resources, increasing the demand for

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

water for domestic uses like drinking and sanitation, irrigation, and industrial purposes. This increased demand puts pressure on the available water resources, leading to water scarcity, particularly during the dry season. Similarly, with a growing population, there is a need to expand agricultural activities to meet the food demand, and the expansion of agricultural land further strains the water resources in the Lake Tana region as agriculture is a major water user. High population growth in the Lake Tana catchment area also often leads to deforestation and improper land use practices, resulting in increased soil erosion, sedimentation, and siltation in the lakes and rivers (Wondie, 2010). This, in turn, affects the water quality and availability, contributing to water scarcity. This high dependency, in turn, has already put high pressure on the basin resources.

Land-Use Change

Land use change has worsened Lake Tana's water shortage situation since it has diminished the lake basin's ability to retain water by turning natural ecosystems into agricultural land and settlement areas. Not only in the Lake Tana catchment, land-use change, demographic growth, and upland soil degradation have transformed land cover into farmlands, grazing lands, human settlements, and urban centres at the cost of East African wetland ecosystems (Mogha et al. 2013). For example, settlement is a growing problem of wetlands around Lake Tana (Ayenew, 2009), and a cause of wetland loss (Sisay, 2003). As a result, the water supplies have been exhausted, and the natural vegetative cover that aids in controlling the water flow has been eliminated, leading to water scarcity. The quantity of sedimentation and pollution in the lake is increased by clearing wetlands and forests, further limiting the lake's water availability. These modifications have increased the demand for water from the lake, which is already having difficulty supplying millions of people, crops, and cattle. Above all, apart from the illegal expansion of farming land by farmers, the local government had officially distributed wetlands to youths for agricultural purposes (BoEPLAU, 2010), and forests and wetlands in the catchment have been continuously declined while the farming lands and settlement area have been increased.

Dams and Irrigation Projects

Human activities combined with population and other socioeconomic factors have caused the lake’s water’s decline, which has decreased the lake level (Mohammed and Mengist, 2018). With the need to meet high energy demand, the Ethiopian government has started to develop hydroelectric power. For example, the Chara Chara-Tis Abbay hydropower plant was constructed using water from Lake Tana in 2002. Since then, unprecedented catastrophic impacts have been exerted on the lake system's physical, ecological, and economic benefits from excess water withdrawal from the lake, accompanied by poor water management and control (Woldegabriel, 2006). In addition, other irrigation projects like Megech, Rib, and Gumara are under construction and will impact the lake's water security problems. These projects will divert water for irrigation purposes and reduce the water inflow to the lake, reducing the water available for multiple uses. Dams constructed on the lake's tributaries also induce sedimentation and can worsen the water storage capacity of the lake. Furthermore, expanding irrigation projects in the region increases water demand and reduces the water available for other uses, including environmental and domestic use. This exacerbates water scarcity problems in the basin. As a result, it can lead to conflicts between different water users, such as farmers and fishers. Irrigation water withdrawals during the dry season are causing water scarcity, conflicts, and environmental damage, especially in the eastern part of the sub-basin.

Water Level Fluctuation Problems of Lake Tana

In addition to the water scarcity problems, Lake Tana also faces water level fluctuations, which could exacerbate the water scarcity challenges (Amare, 2020). These fluctuations have negatively impacted local communities, including

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

problems with continuous water supply and shore degradation. A study conducted by Amare (2020) found that more than 180 km² of Lake Tana area has been converted to farmland and other land uses during the last 35 years, which could be contributing to the water level fluctuations. According to the same author, the lake area has shown an 18.9% decline from 1973 (3019 km2) to 2008 (2829.9 km2). Similarly, Selome (2006) reported a slight decline in lake area from 1987 (3039 km2) to 2001 (2952 km2).

Several studies have been conducted to determine Lake Tana's water balance and to predict water level changes using teleconnections with sea surface temperatures (Yasuda et al., 2022). The hydrology of Lake Tana was a dynamic, changing flow, and there is also evidence that the lake dried up 15,100 and 16,700 years ago and became a papyrus swamp **(**McCann & Blanc, 2016**)**. Similarly, Lamb et al. (2007) reported that recently collected geophysical and core data show nearly 100 m of accumulated sediments in the lake's bottom substrates, and desiccation layers in these sediments indicate that the lake dried out at apparent regular intervals during the later stages of the last Ice Age 10,000–25,000 years ago (Jacobus *et al*., 2009**)**. Then, about 14,750 years ago, water in the entire Nile system seemed to have increased, and the lake overflowed the volcanic blockage into the Blue Nile riverbed again **(**McCann & Blanc, 2016**)**. This process also seems to have happened in the junior partner East Africa's White Nile when Lake Victoria was also in a dry phase (Jacobus et al., 2009**)**. According to the same author, water level trends show three distinct phases of hydrological regime. The first phase covers the period spanning from 1960 to 1973. During this period, the lake water level has decreased by a magnitude of 40 mm/yr. In the second phase (1974 to 1977), the lake water level increased by 220 mm/yr. However, the lake water level declined at a 100 mm/yr rate in the third phase (1978 to 1984). Another recent study by Sintayehu (2018) indicated that the lake's volume has been decreasing at an alarming rate of 0.612 km3/year from 2012 to 2017. According to the same author, the lake will completely disappear within twelve thousand years if no countermeasures are taken.

Causes of Water Level Fluctuations in Lake Tana

A variety of factors, both natural and anthropogenic, can cause water level fluctuations in Lake Tana. Natural factors include climate change, which can affect precipitation patterns and evaporation rates, and seasonal variations in precipitation and runoff. Anthropogenic factors, such as land-use change, water abstraction, dam construction, and water project construction, can also significantly impact the lake's water levels. Climate change is also expected to worsen the water level fluctuations in Lake Tana, with predictions of increasing temperatures and changing rainfall patterns that could reduce water supply to the lake. The drawing of water for hydroelectric power generation is one of the possible causes of the shrinkage of the Lake Tana area and the decline of the lake level (Sewnet & Kameswara, 2011). According to the same author, A drastic (40-45%) and sustained (7-8 years) rainfall reduction is required to change the lake from outflowing to inflowing.

In recent decades, the construction of hydropower dams and irrigation schemes on the lake's tributaries has significantly impacted water level fluctuations in Lake Tana. The increment of the lake water level fluctuation is getting significant after the construction of the Chara-Chara weir (Amare, 2020), which has been constructed to regulate flows for power production at the Tis Abbay power stations and for initial filling of the constructed hydro-dams (Tana Belles). The water diversion for these projects has reduced the amount of water flowing into the lake, causing its water levels to drop. The increased abstraction of water from the lake for agricultural irrigation has also contributed to water level fluctuations. This continuous fluctuation has reduced the lake level, significantly affecting transportation and navigation along the lake and the emergence of a scattering of small islands and a wide-spanning ridge that was previously underwater. It also has further implications for fish's ecological

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

development and migration patterns (Lemoalle et al., 2012).

On the other hand, the Level of Lake Tana varies on a seasonal basis depending on the monthly precipitation. Its area ranges from 3,000 to 3,500 km^2 depending on season and rainfall (Admas *et al*., 2017). Maximum lake level is attained in October, one month after the end of the rainy season, while minimum lake level is attained from May to June. The seasonal rains cause the lake level to fluctuate regularly with an average difference of about 1.5 m between the minimum (May–June) and maximum (September–October) before the Tana Belles hydroelectric power plant has started to operate (Amare, 2020). Because of the significant seasonal variations in the inflow of its tributaries, rain, and evaporation, the water levels of Lake Tana typically vary by 2–2.5 m (6.6–8.2 ft) in a year, peaking in September–October just after the main wet season. When the water levels are high, the plains around the lake are often flooded, and other permanent swamps in the region connect to the Lake (Vijverberg *et al*., 2009).

THE WATER QUALITY PROBLEMS OF LAKE TANA AND ITS MAJOR CASES

Water quality is a dynamic balance of physical, chemical, biological, and hydrological characteristics and processes occurring in an aquatic system that can be defined in terms of certain user functions (Koelmans et al., 2001). Water quality indicators are valuable tools for monitoring the ecosystem integrity and as an indicator of the appropriateness of the water for the intended uses. Lake Tana has shown some undesirable changes in water quality due to loads, dynamics, and impacts of agrochemicals and municipal wastes in the lake ecosystem. Mean nutrient concentrations showed an increasing trend in the lake and its major feeding rivers. The major water quality problems of Lake Tana and their causes are described below.

Sedimentation and Siltation

Lake Tana faces several sedimentation and siltation problems that threaten its ecosystem and the livelihoods of the people in the region (Goshu and Aynalem, 2017). According to the study by Setegn et al. (2009), around 12–30.5% of the watershed in the Lake Tana basin is high erosion susceptible areas. The same author has also reported that the Lake Tana basin is heavily affected by water management problems caused by overpopulation, poor cultivation, improper land use practices, deforestation, and overgrazing. Ayalew (2010) has also reported that 50% of the young age in the catchment area are landless. These landless people create pressure to convert the lakeshore to croplands by deforesting lakeshore vegetation. The wetlands are also being cleared for urbanization and housing, which is causing the loss of critical habitats for wildlife, reducing water storage capacity, and leading to soil erosion. Associated with that, valuable wetlands are being drained and converted into farmland, and reed and papyrus vegetation along its shores is being destroyed. As a result, the lake's buffering capacity to deal with stress is reduced, and the lake is contaminated with millions of tons of chemical fertilizers, pesticide residuals, and sediments (Gebriye et al., 2008).

As a result, sediment deposition in the lakes is becoming a major issue. The lake's rivers and tributaries have gradually eroded the soil, resulting in silt accumulation in the lake. Accordingly, soil erosion and the level of sedimentation and siltation in the lake have increased, resulting in high sediment deposition and nutrient enrichment (average annual sediment yield of 30-65 tons/hectare) (Gebriye et al., 2008). Yitaferu (2007) has also reported that the lake has high silt concentrations with a loading rate of 8.96–14.84 M tons of soil per year. The silt deposits have made the lake shallower and disrupted the water flow.

The sedimentation and siltation problems of Lake Tana have had a negative impact on the lake's ecology, economy, and local communities. The decline in water levels has led to a loss of biodiversity and reduced fish stocks, affecting the lake's food web (Ahmed, 2020). The reduced water flow has also affected hydroelectric and

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

irrigation systems that rely on the lake's water, disrupting the livelihoods of the surrounding communities that depend on Lake Tana for domestic use, fishing, and farming (Kab et al., 2014). Additionally, heavy loads of suspended silt in the rainy season have further increased the turbidity of the lake water, reducing the underwater light intensity and primary production of the lake's ecology (Kebede, 2016; Ahmed, 2020).

Eutrophication

Eutrophication is a phenomenon caused by excessive nutrient accumulation in water bodies, leading to an overgrowth of algae and other aquatic plants. Lake Tana, one of Ethiopia's largest and most important lakes, has been affected by Eutrophication in recent years. Increasing human activities, such as agriculture, urbanization, and industrialization, have contributed to the lake's high levels of nutrients, particularly nitrogen and phosphorus. Moreover, landless people create pressure to convert the lakeshore to croplands by deforesting lakeshore vegetation (Ayalew, 2010). The concentration of nitrate and phosphate in the Lake Tana basin is increasing from time to time (*Table 2*). In addition, waste and effluent from some of the homes, factories, and hotels in urban settlements, including Bahir Dar and Gondar Cities, are released into the lake without any treatment. As a result, the lake trophic status has changed from Oligotrophic to meso trophic (Teshale et al., 2002; Wondie et al., 2007) and then to eutrophic (Fetahi, 2017; Dersseh et al., 2020), especially at shore areas and river mouth of the lake. This is caused by increased phosphorous and nitrogen concentrations from hotels, recreation centres, and nonpoint sources.

The excessive nutrient levels in Lake Tana have resulted in the proliferation of algae and aquatic plants, causing a decline in water quality and ecosystem health. This is due to increased anthropogenic activities, such as sewage discharge and agricultural runoff, which enrich the lake's nutrients and promote algal blooms (Derseh et al., 2021). According to Kebede (2016), the overgrowth of algae and aquatic plants reduces oxygen levels in the lake, leading to the death of fish and other aquatic organisms negatively impacting the fishing industry and tourism. Eutrophication can also lead to harmful algal blooms, which can release toxins and threaten human and animal health (Goshu and Aynalem, 2017).

The physicochemical characteristics of Lake Tana are markedly different at different periods and are summarized in Table 2. Lake Tana has relatively low water temperatures, varying only within small limits (range: 20.8–28.6 °C) (Table 2). The low value of Dissolved oxygen content (3 mgL^{-1}) was recorded in 2011 at Lake Gulf by Goraw (2011), and the high value of dissolved oxygen content (8.18 mgL^{-1}) was recorded in 2016 by Kebede (2016). The pH of Lake Tana ranges from 6.8 to 8.5, which is common for most natural waters. Hence, the pH values of the lake water are within the range of 6.8–8.5, and this value is suitable for normal biological activity, which was set at 6.5 - 8.5 by the European Economic Community (1980). The conductivity of Lake Tana ranges from 100–1000 μS cm^{-1}. The No3, total nitrogen (TN), soluble reactive phosphorus (SRP), Total phosphorus (TP), and total dissolved solids range from 0.2 (2016) to 24.13 mgL^{-1} (2022); 0.92 to 5.6 mgL^{-1}; 0.05 (2013) to 42.4 (2018) mgL^{-1}; 0.07 (2014) to 0.8 mgL^{-1} (2019), respectively (Table 2). The Alkalinity and BOD concentrations in Lake Tana also range from 106.31 to 298.3 mg L−l. and 8.5–226.3 mg L−l., respectively (*Table 2*).

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

Table 2: Physico-chemical parameters of Lake Tana

Physico-chemical parameters	References											
	Dejen *et al*. (2004)	**Akoma (2010)**	**Goraw (2011)**	**Ewnetu et al (2013)**	**Mankiewicz-Boczek *et al*. (2014)**	**Kebede (2016)**	**Tamiru, Sisay (2018)**	**Wondyfraw et al. (2019)**	**Kassa and Tibebe (2019)**	**Dessie *et al*. (2017)**	**Melaku *et al*. (2020)**	**Baye *et al*. (2022)**
Tep (°c)	23.2	22.2–25	20.8–28.6		25	24.92	23.	23.7	23.90	22	23.91	22.5
DO (mg/l)	6.7		3–7.6	6.62		8.18		7.48	4-6.2	5.80	5.9-6.8	6.67
pH	7.7	7.35-8.5	6.8–8.3		8	8.18	7.5	7.75	7.9	7.9	7.2-8	8.25
EC(µScm1)	132.8	152–232	100–1000	171.42	142.7	158	180.1	160.14	148.5	148.5	150.7	158
SRP (mg/l)			0.1–9.1	0.05–2.8		1.03	3- 42.4	0.3	0.1-1.8	0.326	0.04-0.65	0.36
TP (mg/l)		0.10–0.6			0.07-0.47				0.83	0.862		
No3 (mg/l)				6		0.2		0.44	0.1-1	0.763		24.13
No2(mg/l)						0.012						
NH3(mg/l)						0.80						0.25
TN (mg/l)		0.92–4.2			0.6-5.6							
TDS (mg/l)			148–178			73.9	93.1	76.14	94	77.5		77.3
SD (cm)			31–182						84	0.865		
Tur (NTU)			11.2–125			199		14.35				23.35
Alk (mg/l)				106.31		298.3						
Hard mg/l			22–390			286.7		97.28				
BOD (mg/l)			8.5–226.3					0.41				

Notes: Tem=temperature, DO=dissolved oxygen, EC=electrical conductivity, SRP=soluble reactive phosphorus, TP=total phosphorus, TN= total nitrogen, TDS=total dissolved solid, SD=secchi depth, BOD=biological oxygen demand and ALK=Alkalinity

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

Microcystin-Producing Cyanobacteria

Toxigenic bacteria and microcystin-producing cyanobacteria have been found to be a growing problem in Lake Tana, and knowing the presence of these bacteria has particularly significant importance because Lake Tana serves local communities as an essential source of water for drinking, irrigation, and recreation. Microcystin-producing cyanobacteria, predominantly *Microcystis aeruginosa*, and *Microcystis wesenbergii* species, were found in the Bahir Dar Gulf of Lake Tana (Mankiewicz-Boczek *et al*., 2014). Moreover, the detected concentration of *M. aeruginosa* (0.58-2.65 mgL^{-1}) which is greater than the values proposed by the World Health Organization (WHO, 2011) guideline (1 mgL^{-1}) as the maximum concentration of total microcystin-LR and its equivalents in drinking water. The occasional presence of microcystins (≥1 mgL^{-1}) in Lake Tana revealed a serious threat to water quality. It indicated that direct consumption of surface water originating from Bahir Dar Gulf without prior water treatment should be strictly prohibited due to the danger of illness (Mankiewicz-Boczek *et al*., 2014).

Cyanobacteria blooms affect drinking water supply and have a considerable impact on biodiversity and ecosystem functioning, as well as ecosystem services, such as recreation, making the water resource less desirable and even harmful (Anderson *et al*., 2002). These bacteria can produce toxins and cause illness and death if consumed. In addition, these bacteria can negatively impact the fishing industry and tourism, as they pose a risk to fish and other aquatic organisms and can make the lake less attractive to visitors.

Improper Solid and Liquid Waste Management

The expansion of the cities and towns in the Lake Tana watershed and the consequent demand for more and better infrastructure services have created business opportunities in construction, manufacturing activities, service trade, and non-formal trade opportunities. Consequently, hotels and industrial plants with high potential pollution effects are built on the shores of Lake Tana (Teshale, 2002). However, there is no organized site for its solid and liquid waste disposal, and thus, wastes from individual households, hotels, and factories discharged directly into the lake without any treatment. Moreover, Mekonnen (2015) indicated that 20% of Bahir Dar households do not have access to latrines and dispose of wastewater in the accessible open spaces. Only 35% of the city's liquid waste was being collected due to a lack of toilets and poor collection practices. Institutions like Felege hiwot Referral Hospital, Bahir Dar Prison, Bahir Dar University Technology Institute, wastewater from students' cafeterias, and hotels like Ghion, Tana, Avanti, and Grand, etc., release their wastewater directly towards the lake, which in turn produces terrible smells (Mekonnen, 2015). Similarly, Wondyfraw *et al*. (2019) reported that Lake Tana is becoming a sink for dumping municipal, industrial, and domestic wastes from a growing urban population. This has led to pollution and Eutrophication, a decline in water quality, loss of biodiversity, and reduced fish stocks.

Fecal Pollution

Fecal pollution is a severe environmental problem in Lake Tana due to inadequate sanitation facilities and the discharge of untreated sewage into the lake. Waste and effluent from some of the homes, factories, and hotels in urban settlements, including Bahir Dar and Gondar Cities, are released into Lake Tana without treatment. As a result**,** faecal bacteria were observed in the lake, resulting in a decline in water quality and posing a significant threat to human health and safety, especially to the local communities who rely on the lake water for their day-to-day activities. Fecal pollution in Lake Tana poses a risk to local communities' health, and the current water-related disease outbreaks in the basin are most likely to be caused by such problems (Goshu et al., 2017).

The presence of pathogens in the faecal matter can cause diseases such as cholera, typhoid fever, and dysentery, which have been the cause of frequent outbreaks in the region. Studies conducted by

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

Goshu et al. (2010), Yigezu et al. (2015), and Shiferaw and Alabachew (2021) have shown significant levels of faecal pollution in the lake, exceeding permissible limits. According to Goshu et al. (2010), the lake is contaminated with pathogens, Total coliforms (TC), faecal coliforms (FC), Escherichia coli (EC), and Clostridium perfringens (CP), and the level of faecal pollution in the Bahir Dar Gulf of Lake Tana is higher than the WHO standard for drinking and recreation. Similarly, Yemenu (2005) reported significantly increased fecal pollution levels discernible in the Bahir Dar Gulf of Lake Tana.

Heavy Metals Pollution

Lake Tana has been found to be polluted with heavy metals due to various anthropogenic activities. Discharging untreated waste from garages, factories, hospitals, and other agrochemicals and pesticides are the primary sources of heavy metal pollution in Lake Tana (Habiba, 2010). A study conducted by Tadesse et al. (2018) reported the presence of heavy metals such as lead, copper, and zinc in the same lake's water, sediment, and fish samples. Hirut (2014) has reported the values of concentrations of heavy metals in the Lake as Pb ranged from 0.04–42.6 (mgL-1), Cd from 2–19.8 (mgL-1), and Cr from 11–18 (mgL-1). Dagnew et al. (2014) have also reported that the values of Irion (0.37 mgL-1) and Manganese (0.58 mgL-1) are beyond the WHO guidelines (Table 3). Kassa and Tibebe (2019) have also reported that heavy metals such as lead, cadmium, chromium, and zinc levels were above the World Health Organization (WHO) permissible levels for drinking water. Similarly, a study conducted by Wuletaw et al. (2017) has reported that the levels of heavy metals in sediment and fish of the lake exceed the critical limits set by international standards.

The high levels of heavy metals found in the lake pose a risk to the health of local communities who depend on the lake's resources for their livelihoods. For example, the high levels of lead found in some of the fish samples in Lake Tana can pose a threat to human health, as it is a toxic metal that can cause health problems such as anaemia, kidney failure, and developmental delays in children (Engdaw et al., 2022). Additionally, the presence of heavy metals in the lake harms the health and survival of aquatic species, the lake's ecosystem, and the local economy.

Table 3: Some heavy metal features of Lake Tana

Parameters	References					
	Goraw (2011)	**Dagnew *et al*. (2014)**	**Hirut (2014)**	**Kassa and Tibebe (2019)**	**Engdaw *et al*. (2022)**	**WHO Guideline**
Pb (mgL^{-1})			0.04–42.6	0.5		
Cd (mgL^{-1})			2–19.8	0.02		
Cr (mgL^{-1})			11–18	0.14	0.03–0.05	
Fe (mgL^{-1})	2.2	0.37				0.3
Mn (mgL^{-1})	12–17	0.58		1.23		0.4
CU (mgL^{-1})				0.82	0.11-0.17	
Zn (mgL^{-1})				1.35	0.11 to 0.16	

Introduction of Invasive Specious: Water Hyacinth

Lake Tana has experienced an invasion of water hyacinth, which has caused significant ecological and economic problems in the region. The first infestations were found near the mouth of the Megech River on the lake's northern shores, and its infested only 50.5 ha of the lake's surface when it appeared for the first time in 2011 (Wondie et al., 2012). However, since then, the weed grows rapidly and produces enormous amounts of biomass, and its coverage has increased in space and time and infested about nine woredas (Takusa, West Dembia, East Dembia, Gonder Zuria, Libokemkem, Fogera, Dera, Bahir Dar zuria) and about 30 kebeles in riparian area of the lake. Anteneh et al. (2015) reported that water hyacinth coverage escalated from 50.54 ha in

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

2012 to more than 50,000 ha in 2014. According to the same author, Water hyacinth has been expanding broadly, covering more than 130 km of lakeshore length, close to one-third or more than 30% of the lake's shoreline. The shoreline length infestation coverage almost tripled from 2012 to 2014. Similarly, GDTC (2020) reported the temporal dynamics of water hyacinth infestation on Lake Tana from 2012 (50.54 ha) to 2020 (5685.34 ha).

The highly dense mat of the weed affects water quality and availability for domestic uses, including drinking water, livestock watering, and industrial use by making quarrying of wells in lakeshore and by blocking water access and changing its odor. Asmare (2017) and Dersseh et al. (2020) have reported that the highly dense mat of the weed resulted in de-oxygenation of the water, thus disrupting lake ecology and obstructing navigation which has a significant impact on the well-being of local communities. Moreover, the weed's high water content also expedites the evaporation of water from the lake and its associated wetlands, thereby contributing to a further contraction of the lake's areal extent. The dense mats of the plant also provide a favorable environment for mosquitoes and snails, which act as vectors for diseases such as malaria and schistosomiasis, respectively.

Due to the expansion of water hyacinth in Lake Tana, fish resources, including the endemic Barbs, have been in danger, and numbers are reduced on the eastern shore of Lake Tana, where the depth is shallow, and a decline in papyrus has been observed due to water hyacinth (Ketema, 2013; Tewabe, 2015). It deteriorates the lake's fish population because the floating mats limit access to breeding, nursery, and feeding grounds for economically important fish species (Asmare, 2017).

MANAGEMENT OPTIONS

Integrated Watershed Management

Integrated watershed management is an approach that employs collective natural resources conservation measures on a given watershed basis for the benefit of livelihood with sustainable utilization of the resources (Karpuzcu & Delipinar, 2011). Adopting an integrated approach to water resources management can help balance competing water demands and ensure sustainable water use. This approach has been implemented in most parts of Ethiopia for several decades to conserve and rehabilitate watershed resources such as soil, water, forests, rivers, and lakes (Gebregziabher *et al*., 2016). This conservation approach mainly starts implementing its activities from the top of the watershed and goes down to the outlets of the watershed (Lakew *et al*., 2005; FAO, 2017). Therefore, an integrated watershed management approach of the lake and its surroundings should be developed rather than focusing only on the lake itself as conservation of the lake requires covering of watershed and ecosystem bases. It will provide benefits such as rehabilitation of degraded forests, improvement of soil fertility, increase in fodder availability, enhancement of water quality, and improvement ecological integrity (physical, chemical, and biological); hence, integrated watershed management measures are recommended in Lake Tana to improve the degraded ecosystems and their services.

Wetland Conservation

Protecting and conserving the wetlands in the Lake Tana sub-basin is crucial for maintaining the overall health of the lake ecosystem. This can be achieved by establishing protected areas, sustainable land use practices, and community engagement in wetland management. Similarly, Moges (2016) recommended that people's participation and positive attitude toward wetlands are required for sustainable conservation of wetlands. Implementing detailed environmental impact assessments before any form of development (e.g., draining, damming, and diversion) is also needed to ensure that the new modification will not negatively impact the ecology of a wetland area and Lake Tana (Woube, 2008). Furthermore, the absence of a wetland policy and the Ethiopian government's delayed ratification of the Ramsar Convention have also contributed to the unrelieved conversion of

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

wetland ecosystems. Insufficient policy or poor implementation of environmental policies by the governments contribute to wetland degradation (UNEP, 2006). Planting trees, trace building as a controlling method of erosion, and conservation education to the community to be taken to overcome the problems of wetland degradation (Tesfaye, unpublished paper). Thus, a solid conservation-based educational program should be set and implemented to create awareness among the local people on how to manage the wetland to obtain more benefits from it and minimize its destruction. Furthermore, independent wetlands policy development and strengthening cooperation among existing organizations and their enforcement are recommended for sustainable conservation of wetlands.

Buffer Zone Development

Buffer zone development is essential to improving water quality and reducing sedimentation and pollution problems in aquatic ecosystems. Wondie (2010) recommended that the delineation of the buffer zone on the shore of Lake Tana and the bank of its tributary rivers should be made based on habitat character and ecological services using photo technology in defined distance from the lake shoreline and river bank to keep the ecotone intact. Doing so, value-added trees and grasses should be grown to protect the lake from erosion and sedimentation. At the same time, the livelihood of lakeshore communities will be improved by producing perennial grasses and fruit trees. Therefore, commercial buffer zone development is recommended to be developed in the riparian ecosystem of a lake, which benefits both the environment and the land owners or farmers as it can retain nutrients in the soil, thereby increasing yields and the productivity of cash crops, and contributing for improvement of water security of Lake Tana.

Invasive Species Control

Integrated control of water hyacinth is a sensible approach that combines mechanical, biological, and chemical methods that complement each other (GDTC, 2020). Because of the rapid dispersal habit of water hyacinth and the practical constraints and financial costs associated with physical, mechanical, biological, and chemical control measures alone are ineffective for the control of water hyacinth. Thus, integrated management that stresses the weeds over a longer period is usually required for adequate control, particularly for the established infestation. The integrated approach is essential because relying on a single method may not effectively control the invasive plant. For instance, in Malaysia, water hyacinths have been successfully controlled by combining manual removal with biological control (Nai Kin, 1995). Mexico has also successfully removed water hyacinth from Trigomil Dam using a mechanical method integrated with herbicide.

Similarly, the USA successfully controlled the weeds from the water bodies by integrating mechanical and chemical methods. However, using chemical methods is not recommended for Lake Tana because Lake Tana provides drinking water for people in the Islands and other riparian communities. So, using chemicals as water hyacinth control has a negative impact on the lake's water quality, ecosystem, and human health. Indeed, combining mechanical and biological methods is often recommended to achieve the best results in controlling water hyacinths in Lake Tana. By combining these methods, it is possible to reduce the land and water-use impacts of the invasive water hyacinth and improve the health of Lake Tana. For example, mechanical harvesting is used to clear large areas of water hyacinth, while biological control methods are applied to prevent its re-growth (Saha, 2010). In addition, using the weed as a raw material for different purposes like handcrafts, charcoal briquette, animal feeding, biofertilizers, and others is also an important control.

Awareness Creation about the Lake and its Associated Wetlands

Lack of awareness about the functions and values of Lake Tana and its associated wetlands

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

ecosystem has often led to their drastic degradation. Woube (2008) has also reported that awareness about the importance of wetlands in the Lake Tana Sub-basin is virtually lacking. Therefore, public awareness creation is one of the most important ways to conserve the lake and enable the public to be more environmentally conscientious. Increasing public awareness of the environmental degradation and waste problem can reduce the problem at least at an acceptable level. Hence, shoreline and river bank residents should be mindful of trash, phosphate soaps and detergents, paints, and hazardous materials that could leach through the soil and contaminate water bodies. The importance of conserving the lake ecosystem through public awareness campaigns would reach the public. Moreover, awareness creation can be strengthened by forming a lake association to monitor and maintain lake water quality (Wondie, 2010). Therefore, this knowledge gap needs to be bridged by disseminating information to the public about the importance of the lake and associated wetlands, promoting environmental education, and using mass media.

Development Waste Management Practice

Appropriate wastewater management systems (especially in urban and sub-urban areas, including Bahir Dar and Gondar Cities) should be developed instead of directly dumping them into Lake Tana. The waste stabilizing ponds at the municipal level should be developed for the reusable and recyclable wastes for the same or different purposes, to reduce the amount or volume of waste generated from households, institutions, industries, agricultural and commercial sites, and to create clean energy from wastes and replace the dirty energy (Goshu *et al*., 2017; Wondyfraw *et al*., 2017). Creating public awareness at all levels regarding environmental health and providing feedback to policymakers on the pollution status of the water resource is also essential for waste management.

Enforcement of Environmental Related Policies and Strategies

Though policies like water and environment aim for sustainable development, their enforcement is lacking, resulting in many adverse impacts on the environment (Teshale *et al*., 2002). So, Environmental and water policies should be implemented, and effluent standards and enforcement mechanisms should be established. The respective municipalities should control point source waste before releasing it into the lake. Due to the high contamination potential of sewage, illegal and unsanitary waste disposal systems should not be practiced, and each point source of pollution should control and treat its waste, for example, by waste stabilization ponds or engineered wetlands. Environmental Impact Assessment (EIA) as a tool should also be practiced before any development project is implemented to compromise development and the environment.

CONCLUSIONS

Understanding water characteristics regarding water level and quality is vital for water resources development and environmental protection plans and management. Available data on the water quality assessment of Lake Tana and its environs indicated that the water characteristics in the lake are affected by anthropogenic and natural factors but mainly by human activities from point and diffuse sources. Although only a limited data set in terms of time and space has been established, it is clear that anthropogenic activities significantly influence the lake's water quantity and quality. Multiple problems like sedimentation, Eutrophication, faecal pollution, heavy metal pollution, toxin producing bacteria detection, and hydrological alterations showed this. Results urgently call for further research and continuous data generation concerning the lake area, surrounding wetlands, and tributary rivers. As an immediate first step in establishing good knowledge of the general situation of lake water security, simple monitoring programs based on a good and practical selection of robust physical, biological, and hydrological indicators and basic

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

chemical parameters are urgently needed. Different lake ecosystem management options like delineation of buffer zones, awareness of the lake's importance, development of waste management practice, eradicating/reducing water hyacinth, enforcement of Environmental policies and Strategies, and creating integrated watershed management are recommended for sustainable management of Lake Tana.

REFERENCES

Ahmed, H. (2020). Mapping and examining the spatiotemporal trend of turbidity: A remote sensing perspective over Lake Tana, Blue Nile Basin, Ethiopia (Doctoral dissertation).

Amare S. M. (2020). Water level fluctuations of Lake Tana and its implication on local communities livelihood, northwestern Ethiopia. *International Journal of River Basin Management*, *18*(4), 503-510.

Anderson, D. M., Glibert, P. M., & Burkholder, J. M. (2002). Harmful algal blooms and Eutrophication: nutrient sources, composition, and consequences. *Estuaries*, *25*, 704-726.

Anteneh, W., Dereje, T., Addisalem, A., Abebaw, Z., & Befta, T. (2015). Water hyacinth coverage survey report on Lake Tana. *Bahir Dar University: Bahir Dar, Ethiopia*.

Asmare, E. (2017). Current Trend of Water Hyacinth Expansion and Its Consequence on the Fisheries around North Eastern Part of Lake Tana. *Ethiopia. J Biodivers Endanger Species*, *5*, 189.

Ayenew, T. (2009). *Natural lakes of Ethiopia*. Addis Ababa: Addis Ababa University Press.

Dagnew, M., Mingist, M., Getahun, A., & Anteneh, W. (2014). Spawning migration of Labeobarbus species of Lake Tana to Gilgel Abay River and its tributaries, Blue Nile Basin, Ethiopia. *African Journal of Fisheries Science*, *2*(9), 176-184.

Dejen, E., Vijverberg, J., Nagelkerke, L. A., & Sibbing, F. A. (2004). Temporal and spatial distribution of microcrustacean zooplankton in relation to turbidity and other environmental factors in a large tropical lake (L. Tana, Ethiopia). *Hydrobiologia*, *513*, 39-49.

Dersseh, M. G., Tilahun, S. A., Worqlul, A. W., Moges, M. A., Abebe, W. B., Mhiret, D. A., & Melesse, A. M. (2020). Spatial and temporal dynamics of water hyacinth and its linkage with lake-level fluctuation: Lake Tana, a sub-humid region of the Ethiopian highlands. *Water*, *12*(5), 1435.

Dessie, M., Verhoest, N. E., Adgo, E., Poesen, J., & Nyssen, J. (2017). Scenario-based decision support for an integrated management of water resources. *International Journal of River Basin Management*, *15*(4), 485-502.

EEC (European Economic Community) (1980). EC Drinking Water Standards. Directive 80/778/EEC. https://en.wikipedia.org/wiki/European-Economic-Community.

Ewnetu, D. A., Bitew, B. D., & Chercos, D. H. (2013). Determination of surface water quality status and identifying potential pollution sources of Lake Tana: particular emphasis on the lake boundary of Bahirdar City, Amhara region, north west Ethiopia, 2013. *J Environ Earth Sci*, *4*(13), 88-97.

GDTC (2020). *Water Hyacinth: a threat to Lake Tana*. Bahir Dar University, Bahir Dar, Ethiopia

Gebriye S. S. (2008). *Hydrological and sediment yield modelling in Lake Tana basin, Blue Nile Ethiopia* (Doctoral dissertation, KTH).

Goshu G (2011). Annual Report on Lake Tana water quality base line monitoring. Tana Beles Integrated Water Resources Development Project, Bahir Dar.

Goshu, G., & Aynalem, S. (2017). Problem overview of the lake Tana basin. *Social and ecological system dynamics: Characteristics,*

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

trends, and integration in the Lake Tana Basin, Ethiopia, 9-23.

Goshu, G., Byamukama, D., Manafi, M., Kirschner, A. K., & Farnleitner, A. H. (2010). A pilot study on anthropogenic faecal pollution impact in Bahir Dar Gulf of Lake Tana, Northern Ethiopia. *Ecohydrology & Hydrobiology*, *10*(2-4), 271-279.

Goshu, G., Koelmans, A. A., & de Klein, J. J. M. (2017). Water quality of Lake Tana basin, Upper Blue Nile, Ethiopia. A review of available data. *Social and Ecological System Dynamics: Characteristics, Trends, and Integration in the Lake Tana Basin, Ethiopia*, 127-141.

Hirut, G. (2014) Proximate analysis & Determination of heavy metals from water & common fish species in Lake Tana. *MSc thesis, Addis Ababa University*.

Howell, P. P., & Allan, P. (1994). The Nile: Sharing a scarce resource: A historical and technical review of water management and of economical and legal issues.

Kassa, Y., & Tibebe, D. (2019). Analyses of potential heavy metals and physico-chemical water quality parameters on Lake Tana, Ethiopia. *Journal of Academia and Industrial Research (JAIR)*, *8*(7), 130-138.

Kebede, Y. W. (2016). Water quality status of Lake Tana, Ethiopia. *Journal of Civil and Environmental Research*, *8*(9), 39-41.

Ketema, D. M. (2013). *Analysis of institutional arrangements and common pool resources governance: the case of Lake Tana sub-basin, Ethiopia* (Doctoral dissertation, University College Cork).

Koelmans, A. A., Van der Heijde, A., Knijff, L., & AALDE-RINK, R. H. (2001). Modelling feedbacks between Eutrophication and organic contaminant fate & effects in aquatic ecosystems. *Rev Water Res*, *35*, 3517-3536.

Lamb, H. F., Bates, C. R., Coombes, P. V., Marshall, M. H., Umer, M., Davies, S. J., & Dejen, E. (2007). Late Pleistocene desiccation of Lake Tana, source of the Blue Nile. *Quaternary Science Reviews*, *26*(3-4), 287-299.

Lemoalle, J., Bader, J. C., Leblanc, M., & Sedick, A. (2012). Recent changes in Lake Chad: Observations, simulations, and management options (1973–2011). *Global and planetary change*, *80*, 247-254.

Mankiewicz-Boczek, J., Gągała, I., Jurczak, T., Urbaniak, M., Negussie, Y. Z., & Zalewski, M. (2015). Incidence of microcystin-producing cyanobacteria in Lake Tana, the largest waterbody in Ethiopia. *African Journal of Ecology*, *53*(1), 54-63.

McCann, J., & Blanc, G. (2016). Bahir Dar and the lake Tana basin: History of an urbanshed. *Etudes rurales*, 113-124. http://journals.openedition.org/etudesrurales/10659; DOI: 10.4000/etudesrurales.10659.

Mekonnen, G. (2015). Characterization of agricultural soils in Cascape intervention Woredas of Amhara Region. *Wageningen, NZ*.

Mohammed, I., & Mengist, M. (2018). Status, threats and management of wetlands in the lake Tana sub-basin: a review. *Journal of Agriculture and Environmental Sciences, 3*(2).

Poppe, L., Frankl, A., Poesen, J., Admasu, T., Dessie, M., Adgo, E., ... & Nyssen, J. (2013). Geomorphology of the lake tana basin, ethiopia. *Journal of Maps*, *9*(3), 431-437.

Seifu, K., Travi, Y., Alemayehu, T., & Marc, V. J. J. O. H. (2005). Water balance of Lake Tana and its sensitivity to fluctuations in rainfall, Blue Nile basin, Ethiopia. *Journal of hydrology*, *316*(1-4), 233-247.

Selome, M. (2006). *Assessment of Temporal Hydrological Variations Due to Land Use Changes Using Remote Sensing and GIS: A Case Study of Lake Tana Basin*.

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

Setegn, S. G., Srinivasan, R., Dargahi, B., & Melesse, A. M. (2009). Spatial delineation of soil erosion prone areas: application of SWAT and MCE approaches in the Lake Tana Basin. *Ethiop Hydrol Process Spec Issue Nile Hydrol*, *23*(26), 3738-3750.

Sewnet, A., & Kameswara, K. R. (2011). Hydrological dynamics and human impact on ecosystems of Lake Tana. *Northwestern, Ethiopia doi*, *10*.

Sheferaw, H. A., & Atlabachew, M. (2021). Review of characterization, factors, impacts, and solutions of Lake eutrophication: lesson for lake Tana, Ethiopia. *Environmental Science and Pollution Research*, *28*(12), 14233-14252.

Sitotaw, B., Daniel, B., Kibret, M., & Worie, W. (2022). Seasonal Dynamics in Bacteriological and Physicochemical Water Quality of the Southern Gulf of Lake Tana. The Scientific World Journal, 2022. https://doi.org/10.1155/2022/7317702.

Tadesse, F. (2019). Eutrophication of Ethiopian water bodies: a serious threat to water quality, biodiversity and public health. *African Journal of Aquatic Science*, *44*(4), 303-312.

Tamiru, S. M. (2018). *Assessment of the impact of anthropogenic activities on water quality, biodiversity and livelihood in Lake Tana, Northwestern Ethiopia* (Doctoral dissertation, Doctoral dissertation. University of South Africa. https://uir. unisa. ac. za/bitstream/handle/10500/25240/thesis_tamiru_sm. pdf).

Teferi, M. T., Haile, A. T., Fekadu, A. G., & Nakawuka, P. (2021). Effect of irrigation water withdrawal on the hydrology of the Lake Tana sub-basin. *Journal of Hydrology: Regional Studies*, *38*, 100961.

Teshale, B., Lee, R., & Zawdie, G. (2002). Development initiatives and challenges for sustainable resource management and livelihood in the Lake Tana region of Northern Ethiopia. *International Journal of Technology Management & Sustainable Development*, *1*(2), 111-124.

Tewabe, D. (2015). Preliminary survey of water hyacinth in Lake Tana, Ethiopia. *Global Journal of Allergy*, *1*(1), 013-018.

Vijverberg, J., Sibbing, F. A., & Dejen, E. (2009). Lake Tana: source of the blue nile. In *The Nile: Origin, environments, limnology and human use* (pp. 163-192). Dordrecht: Springer Netherlands.

Wondie A. (2012). Biodiversity and ecosystem services of lake Tana Wetlands, Ethiopia. In: Seyoum M, Tadesse F (eds) 2nd National workshop, Bahir Dar, January 2012. Preliminary Assessment of Water hyacinth in Lake Tana, pp 117–135.

Wondie, A. (2010). Improving management of shoreline and riparian wetland ecosystems: the case of Lake Tana catchment. *Ecohydrology & Hydrobiology*, *10*(2-4), 123-131.

Wondie, A., Mengistu, S., Vijverberg, J., & Dejen, E. (2007). Seasonal variation in primary production of a large high altitude tropical lake (Lake Tana, Ethiopia): effects of nutrient availability and water transparency. *Aquatic Ecology*, *41*, 195-207.

Wondyfraw, M., Suneetha, P., & Krishna, T. V. (2019). The impact of infrastructure development on lake tana water quality, *Journal of Emerging Technologies and Innovative Research*:6, SSN-2349-5162.

Woube, M. (2008). The role of Wetlands in Biodiversity Conservation and Management in Ethiopia: a case study of Berga Floodplain. In *An overview in Proceedings of the National Stakeholders' Workshop on Creating National Commitment for Wetland Policy and Strategy Development in Ethiopia Shimeles Sima and Geremew G/Selassie (eds)*.

Wubneh, M. A., Worku, T. A., Fikadie, F. T., Aman, T. F., & Kifelew, M. S. (2022). Climate change impact on lake tana water

Article DOI: https://doi.org/10.37284/eajenr.6.1.1631

storage, upper blue nile basin, Ethiopia. *Geocarto International*, *37*(25), 10278-10300.

Yasuda, H., Fenta, A. A., Berihun, M. L., Inosako, K., Kawai, T., & Belay, A. S. (2022). Water level change of Lake Tana, source of the Blue Nile: Prediction using teleconnections with sea surface temperatures. *Journal of Great Lakes Research*, *48*(2), 468-477.

Yemenu, A. (2005). *Characterization of domestic waste water disposal as point source pollution in southern Gulf of Lake Tana, Northwestern Ethiopia* (Doctoral dissertation, MSc. Thesis, Environmental Science Program, School of Graduate Studies, Addis Ababa University, Addis Ababa, Ethiopia).

Yitaferu, B. (2007). *Land degradation and options for sustainable land management in the Lake Tana Basin (LTB), Amhara Region, Ethiopia* (Doctoral dissertation, University of Bern).

