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Review Article

Problem of Water Hyacinth (*Eichhornia crassipes* (Mart.)) in Lake Tana (Ethiopia): Ecological, Economic, and Social Implications and Management Options

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Lake Tana is Ethiopia's largest body of fresh water, covering approximately 3,200 km^2. Despite its multidisciplinary applications in Ethiopia and neighboring countries, water hyacinth (*Eichhornia crassipes* (Mart.) Solms) is a significant problem in this large lake. This invasive weed first appeared in Lake Tana in 2011 and quickly spread to the water's surface over the next two to three years. In this background, this article aims at reviewing the existing knowledge on the occurrence, impact, and management options for water hyacinths in Lake Tana. Water hyacinth is one of the most dangerous water weeds, causing a wide range of problems in bodies of water and water resources, including ecological, environmental, economic, and social consequences. Due to the weed species' rapid spread via sexual and asexual reproduction, it covers a wide range of water bodies, and appropriate management options must be implemented before seriously affecting the water body and spreading to the Nile Basin.

1. Introduction

Lake Tana is located on the basaltic plateau of Ethiopia's northwestern highlands, covering an average area of 3,200 km^2 at an elevation of 1,830 m with an average depth of 8 m [1]. It is the largest freshwater body in the country and the third-largest lake in the Nile Basin. It is also one of the most important catchments in the Nile Basin, which is formed by the Abay River [2]. Lake Tana is of significant ecological, religious, historical, and economic importance, and due to its rich biodiversity and cultural and historical significance, it was designated a United Nations Educational, Scientific, and Cultural Organization (UNESCO) Biosphere Reserve in 2014 [3]. Lake Tana has a variety of uses, including fishing, electric power generation, transportation, drinking water for humans and animals, and a habitat for various birds [4]. Lake Tana's diverse aquatic ecosystems (lake, wetlands, and rivers) support unique endemic fish species; 20 of Lake Tana's 27 fish species are endemic to this lake's catchment [5]. Lake Tana is not only an economic and cultural source for Ethiopians but also an economic source for Egypt and Sudan. However, water hyacinth weed has become a challenge for the ecology of this lake [4].

Water hyacinth is a free-floating perennial aquatic plant native to tropical and subtropical South America, with bright green, waxy leaves and lovely violet flowers with yellow stripes on the banner petals [5]. It can grow up to 1 meter above the water's surface and has an 80 cm root below the water's surface. It reproduces primarily through runners and stolons, and each plant can also produce thousands of seeds per year, which can live for more than 28 years [6]. In Ethiopia, the water hyacinth first appeared in 1965 at the Koka reservoir and in the Awash River. It has been observed on the lake's edges since 2011, and in 2014, it covered more than 500 km^2 of water surface [7]. Water hyacinth (*Eichhornia crassipes*) is one of the most dangerous invasive water weeds, causing various problems for millions of people who use water bodies and water resources for a wide variety of

ecological, economical, and social purposes [8]. In this background, this article aims at providing an overview of the occurrence, impact, and management options for water hyacinths in Lake Tana, Ethiopia.

2. Occurrence and Distribution of Water Hyacinth

Water hyacinth is believed to have been first observed in the Awash River and Lake Koka 77 years ago in Ethiopia [9]. The exact source of the water hyacinth infestation in Lake Tana is unknown. Still, some schools of thought believe it arrived via the importation of used fishing gear, migratory birds, second-hand agricultural inputs, and fishing boats from Sudan and other neighboring countries [10]. Due to a lack of natural enemies, an abundance of space, favorable temperature conditions, and abundant nutrients on the water's surface, it spreads rapidly [11]. Free grazing of wetlands and recession of agricultural land appears to degrade buffer zones, which leads to rivers flowing into the lake, and the lake is a recipient of various wastes such as heavy loads of soil sediment, drain pesticides, urban pollution, and pollutant chemicals. Additionally, substantial application of fertilizer in the catchment's agricultural areas and discharge of municipal solid waste without treatment from the nearby cities of Gondar and Bahir Dar to the lake are likely to aggravate and facilitate the infestation [1, 12].

Water hyacinth grows and spreads quickly in freshwater bodies and can withstand nutrient deficiency, pH, temperature, and toxic water. Water bodies enriched by agricultural chemicals, sediments from catchment erosion, domestic effluents, and plant nutrients aid its invasion [13]. Water hyacinth can also spread through plant fragmentation and resprout from rhizomes, stolons, or germinates from seeds [14]. Seed dispersal is also aided by waterborne seeds and migratory birds. The floating nature of the weed on the water bodies due to various pushing factors such as higher wind velocity, water movement, and sexual and asexual reproduction capability of this weed contributed to its speedy distribution in Lake Tana [9].

Water hyacinth first appeared and was officially reported in Lake Tana in 2011 at the northern tip of the lake called Megech after a higher accumulation of nitrogen in the lake (Figure 1) [15–17]. It is projected that the greatest effective surface area of Lake Tana that was predicted to be impacted by the invasive weed is around 248 km^2 (24,800 ha), or approximately 8% of the total lake area [12]. Mainly, the lake's northern shore has a large flood plain (nearly 5759 ha), which is more susceptible to weed invasion [12]. This might be due to large areas of flood plain and shallow lake depth, along with a higher contribution of sedimentation, waste disposal, increased salinity, and the accumulation of higher total phosphorus and nitrogen from agricultural fields. Time series analysis of the data reveals that the area typically invaded by the weed increases after the rainy season and decreases at the end of the dry season, which is consistent with seasonal trends observed in other tropical water bodies [18]. The area invaded by the weed varies season to season, and a higher area (30, 728.4 ha) was recorded in the rainy season of August [12]. In contrast, mainly from October to December, the infestation level was found to increase [16]. Concurrently, autumn (the post-wet season) has the maximum area coverage of water hyacinth, whereas summer (the primary rainy season) has the lowest invasion [19]. This shows that the distribution of the weed is higher in the late period of the rainy season.

Water hyacinth is a fast-growing aquatic weed that has expanded rapidly at times and forms large mats (Figure 2) [20]. For example, between 2013 and 2015, the coverage area increased by 50%, and between 2015 and 2017, it increased by 82 percent. Because the weed spreads quickly and threatens the water's existence, some immediate and appropriate intervention mechanisms need to be implemented. Some evidence shows that the area covered by water hyacinth in 2011 was about 80 to 100 hectares, and then, it spread to the eastern part of the lake and reached an area of 50,000 hectares in 2017 [21]. Later, in 2019, the coverage of water hyacinth declined to 11.22 km^2 [16]. However, the spatial coverage of water hyacinth using advanced study tools (machine learning approaches) revealed a decreased invasion of the weed by 63.6% in the winter of 2022-2023 and by 46.3% in the autumn of 2021-2022 [19]. Surprisingly, recent reports show that the current infestation level of water hyacinth has dramatically declined to 1% of the total coverage [17]. This could be due to the various bodies' contributions, such as the mass movement of the surrounding community (seasonal campaigns) (Figure 2), some attention from the local government, and the use of multipurpose big machinery (water hyacinth uprooter and crusher). Additionally, the awareness of the nearby farmers in managing their lands that reduces the inlet of chemicals, sediments, fertilizer components, and the use of integrated watershed management in nearby catchment areas have contributed to the reduction of the weed.

3. Impacts of Water Hyacinth in Lake Tana

3.1. Ecological and Environmental Impact of Water Hyacinth

3.1.1. Direct Effects. The expansion of water hyacinth in the water bodies could result in various direct and indirect effects on the ecology and environment. Water hyacinth flowers all the year round and produces at least 3000 seeds per year, which is a very fast dispersal rate when compared to other aquatic weeds, and each seed is viable for up to 20 years. Although water hyacinth seeds may not be viable in all locations, water hyacinth frequently settles in new spaces through vegetative reproduction and the propagation of horizontally growing stolons. For instance, water hyacinth's high density causes deoxygenation of the water, affecting all the aquatic organisms and increasing evapotranspiration, which increases water losses from the lake [21]. Dense water hyacinth mat blocks heat exchange between the lake surface and the atmosphere, slightly increasing temperature through heat generated by decaying organic matter from water hyacinth [22]. The dissolved oxygen level in underwater hyacinth decreases as the temperature rises, owing primarily to the metabolic activity of epiphytic organisms [22, 23]. The density of copepods was higher in the weed-infested site, while rotifers contributed significantly more in the

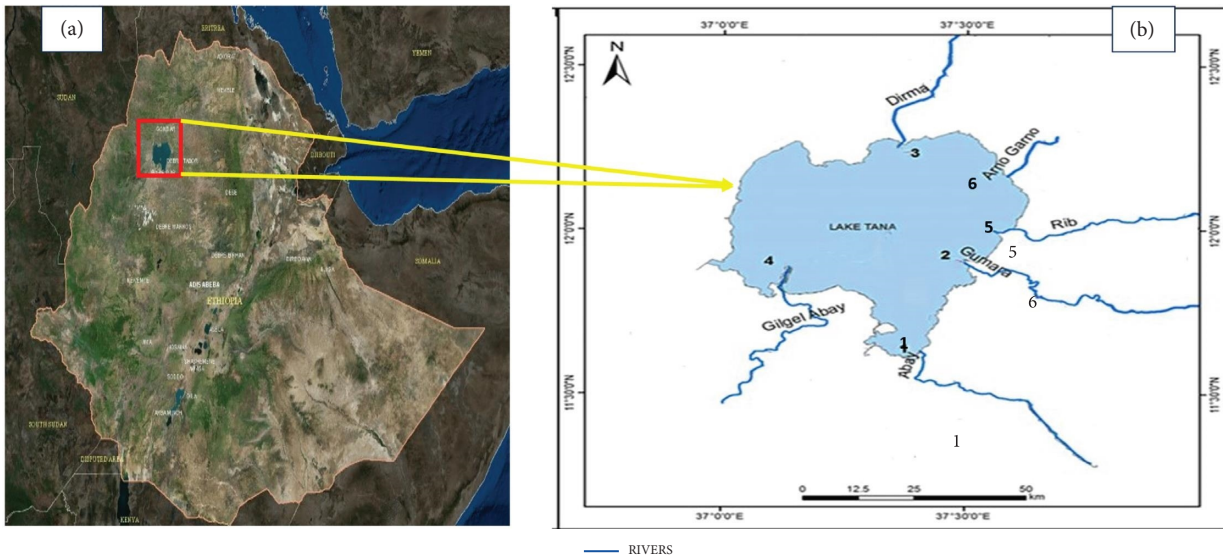

Figure 1: Geographical location of Lake Tana. (a) Map of Ethiopian from East Africa; (b) Lake Tana situated in northwestern region of Ethiopia called Amhara region (the place highlighted by red color is Lake Tana).

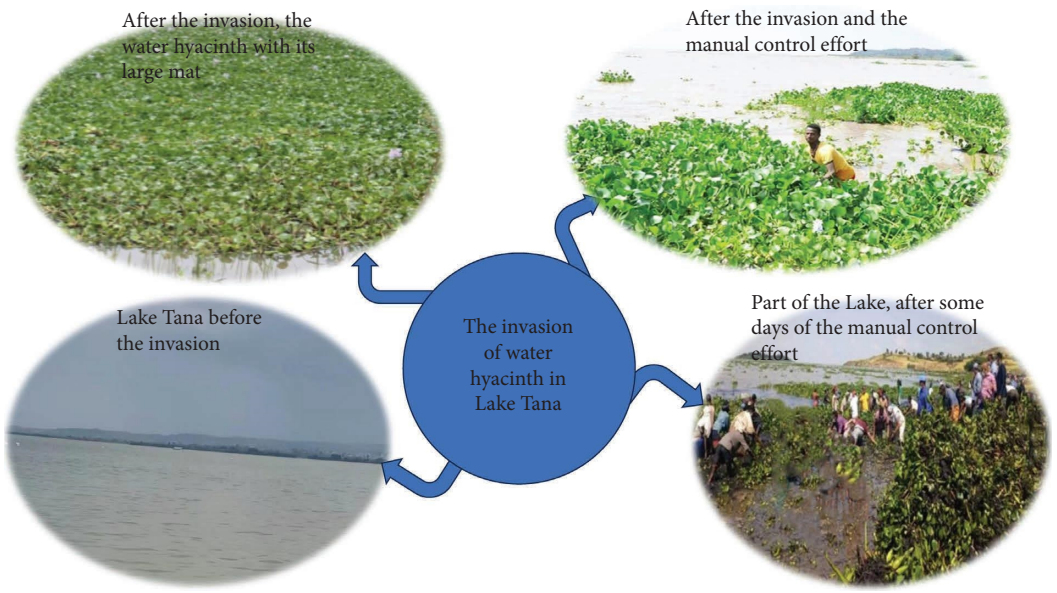

Figure 2: The invasion of water hyacinth in Lake Tana and community participation in the weed control.

noninfested site [21]. However, statistically nonsignificant differences were observed in the physicochemical characteristics of the lake's water between weed-infested and -noninfested sites in Lake Tana [21]. Generally speaking, the effects of *Eichhornia crassipes* on the physicochemical characteristics of water are characterized by a decrease in temperature, reduction of light penetration to the water body, reduced pH, increased biological oxygen demand (organic load), and nutrient levels (accumulation of excessive nitrogen and total phosphorus). In line with this, studies have shown that the total phosphorus (TP) concentration was increased by 5–10 fold (0.2 mg/L–1.8 mg/L) from 2014–2020 [17]. Similarly, the ratio of total nitrogen (TN) to total phosphorus (TP) increased from 0.4 to 29.5 after the weed infestation in Lake Tana. Apart from biodiversity and ecological imbalance, the expansion of this plant results in a higher rate of evapotranspiration and, if it covers large areas, eventually leads to the drying up and shrinking of the lake [24]. In general, the direct effects of water hyacinth include the decline of water quality (negative pressure on chemical, physical, and biological composition), competition for air, space, and nutrients, the release of poisonous compounds, becoming a barrier for fishing, and transportation, leading to the development of indirect effects.

3.1.2. Indirect Effects. The direct effects of this weed such as occurrence of low dissolved oxygen increase conditions that catalyze the release of phosphorus from sediments, accelerating eutrophication, and increasing the growth of water hyacinth or algal blooms [25]. Besides, there could be an accumulation of toxic compounds in the lake that impacts the water quality for irrigation, drinking, and aquatic animals' diversity. The water quality is affected by decreasing pH, dissolved oxygen, and light levels while increasing CO_2 tension and turbidity [17]. Then, invasive water hyacinth alters the natural diversity and balance of ecological communities. Weeds compete with native plants for space, nutrients, and sunlight, threatening the survival of many plants and animals. This reduces biological diversity, has an impact on native submerged plants, changes immersed plant species by pushing them away and competing them out, and also changes animal communities by blocking access to water and/or causing elimination of plants they feed up on [20]. By limiting the growth of other submerged macrophytes, water hyacinth creates a highly complex habitat structure. This modification and complexity of habitat at the water's surface affects the lives of fish and other invertebrates. Because of its rapid reproductive ability, the weed also outcompetes indigenous species, posing a threat to aquatic biodiversity [26]. In this regard, a recent study in Nepal has shown that the presence of water hyacinth has a negative effect on the abundance of native fish species, which may be due to a decline in water quality [27]. Besides, their study showed that native fish species were reduced due to an inverse relationship between physicochemical properties such as transparency, pH, and dissolved oxygen levels and a close relationship between carbon dioxide levels and water hyacinth coverage. Therefore, it can be concluded that water hyacinth could inversely affect the ecology and biodiversity of aquatic bodies. The ability of the weed to grow in a variety of aquatic environments, such as ponds, lakes, streams, ditches, and rivers, as well as in both warm and cold climates, poses a threat to the ecological stability and biodiversity of the aquatic fauna of the water bodies [28].

The most visible environmental impact of water hyacinth infestations that directly affects the riparian community is water quality degradation caused by its foul odor and debris [29]. The quality of water and its suitability for different uses are defined by its physical, chemical, and biological constituents. These components are affected by various factors such as stormwater run-off, nitrification from decaying matter, water hyacinth, toxic and hazardous substances, oils, fats, litter, rubbish, and land use such as industrialization, agriculture, mining, and forestry activities, which contribute significantly to the degradation of water quality [30]. The water quality parameters are significantly different and depend on the end-use objectives. Although the quality components considered for irrigation, fishery, drinking water, and other industrial purposes are different, pH, EC, TSS, DO, and turbidity are frequently considered [31]. Considering these things, water hyacinth is a major threat to Lake Tana and the surrounding communities, contributing to the pollution of water bodies. The EC values (91–1048 μS/cm) were lower than the standard limit for surface water (1275 μS/cm), while the dissolved oxygen (DO) was higher than the tolerance level (4 mg/l) for standard surface water, and the turbidity ranged from 5.57 to 25.9 NTU in the infested areas [31]. Due to the constant rotting of the mat base, thick water hyacinth mats increase water turbidity. The weed also has an impact on the diversity, distribution, and abundance of aquatic life. Recent studies have shown that the impact of water hyacinth on water quality is beyond the standards of the WHO [30].

Furthermore, water hyacinth reduces the oxygen level of the water body and increases evapotranspiration, affecting all aquatic organisms. The death and decay of large masses of water hyacinth vegetation create anaerobic conditions and the production of lethal gases [32]. Most of the anaerobic decomposition process produces lethal gases consisting of methane (CH_4) and carbon dioxide (CO_2), which are toxic to the environment and even responsible for global warming. Therefore, the overall direct effects could lead to indirect effects such as reduction in biodiversity, increased global warming, and economical, ecological, and social problems.

3.2. Economic Impact of Water Hyacinth. Water hyacinth covers a significant proportion of Lake Tana and impacts the economic conditions of thousands of rural households. When the water body shrinks during the summer months, the water hyacinth stays on the farm by penetrating its long root into the ground, making the farmland more compacted and difficult to plough [21]. Due to this, the farmers also spend a significant amount of time and money preparing their farmland for crop planting. Another issue associated with water hyacinth infestation is that farmers use the collected water hyacinth as a terrace from various locations and around the boundary of their land. The collected water hyacinth (heap) also has an impact on farm management because it occupies a large space and makes farmland vulnerable. Dense water hyacinth infestations reduce water flows in rivers and irrigation channels by 40–95 percent, interfering with irrigation equipment and causing structural damage to bridges [33]. Reduced irrigation flow can indirectly impact field crops, but it can also have an immediate impact on paddy crops (rice) by suppressing the crop, inhibiting germination, and interfering with harvesting [23]. According to the recent studies, water hyacinth covered 33.4% of the farmers agricultural land considered for the survey, and the weed covered 0.41 hectares on average of the affected households' land [8]. The weed's spread across the agricultural area has various connected effects. The primary cause is decreased household crop production, particularly rice and other crops grown around the lake. According to their analysis, the annual cost of crop decline resulting from water hyacinth was projected to be 19819.3 Ethiopian birr (ETB) on average.

Additionally, this study indicated that crop production in terms of rice equivalent has been reduced in water hyacinth-infested fields (1798.1 kg) than in noninfested land (3043.1 kg) per household. Due to this, households may lose more than half (55.2%) of their annual income or around 14724 Ethiopian Birr. Similarly, a very close estimation of

income loss was also reported by Enyew and his friends [34]. More than 2900 fishers were at risk due to the decline of fish sources impacted by the weed infestation in the lake [34]. Additionally, their survey result demonstrated that each fisher lost 48 USD per day compared to the income he/she could earn before the weed's infestation time (in 2010). They were also forced to incur an additional cost of nearly 117 USD per year for weed control after the weed-infested years of fishing. Likewise, the recent study data show that the reduction in fish production was 45.7% in the wet season and 49.9% in the dry season, while the reduction in crop production (278.7–475.4 kg rice equivalent) and livestock production (0.083–0.114 tropical livestock unit (TLU)) of the affected household was due to water hyacinth [8]. According to studies, between 2012 and 2018, nearly 800,000 man-hours were spent on manual weed removal, and more than $1 million will be spent on purchasing harvesting equipment and bioagent trials [34]. More than 3.2 million USD has been invested, and nearly 0.8 million workers have been involved in controlling Lake Tana's water hyacinth. The cost of such a large amount of money significantly impacts the economic situation of the government and the local community.

Furthermore, the spread of water hyacinth mats can adversely affect the economics of fisheries and fish catch rates by blocking access to fishing grounds, clogging and damaging net eyes, and increasing fishing costs (effort and materials) [32]. This aquatic weed also tears gill nets and damages the boat's motor, increasing the cost of fishing. Fisherman spends extra time after catching water hyacinth parts from gillnets. Fisherman set up a gill net in an uninfected area, but when the wave arrives, the fishing gear is covered by water hyacinth, and the gill net is lost. If they lose their gill net, they may have to spend more time and money looking for it and repairing it. In general, water hyacinth infestation has reduced fishing efficiency in the study area [21]. The expansion of water hyacinth and its competition with native species have devastated submerging grasses and other native species [35]. According to their assessment, some farmers buy supplementary feeds for their cattle because the invasive water hyacinth has destroyed the grass on the grazing lands around the lake. The most important grass species that were used for livestock grazing are destroyed by the massive water hyacinth mats including Serdo (*Cynodon dactylon* (L. Pers.) and asindabo (*Echinochola pyramidalis*) [34]. These could impact a large number of cattle, which are both directly and indirectly dependent on the grass around the lake. The infestation of the weed would generally have a direct effect. For example, the weed infestation makes the farmers land compacted and difficult to plough, the weed collection (heap) takes up more space, it clogs and interferes with the movement and flow of irrigation water in the canals and terraces, and mostly the weed covers more crop production areas, resulting in the land being out of production. This indirectly affects the farmers to incur more energy and money to plough the compacted land; the heap makes it difficult to plough and also takes up more space; reduced movement of water affects crop growth and productivity; and it majorly affects the livestock and crop production. Accordingly, the affected area communities or farmers could lose a lot of money because of their land being out of production and incur a lot of money for the management of the weed to reduce its impact. Overall, the things mentioned above significantly affect the economic status of the farmers engaged in livestock production, and fish production, transportation services, and crop cultivation.

3.3. Social Impacts of Water Hyacinth. The infestation of water hyacinth (*Eichhornia crassipes*) at large can have direct effects on the community leading to social impacts. Because the weed creates excellent breeding sites for mosquitoes and other insects, there is a general increase in several diseases where these are in abundance. These direct effects again result in indirect effects on the people such as rising cases of skin rashes, coughs, malaria, encephalitis, bilharzias, gastrointestinal disorders, and schistosomiasis [36]. Besides, as a consequence of the direct effects of water hyacinth, the indirect effects such as social conflict, illness, availability of lower water quality, and reduced water availability for irrigation are major treats [34]. Through the blockage, water hyacinth interferes with the water intake points, lowering the amount of water pumped. Furthermore, as the water level drops, the villagers are bothered by the unpleasant odor of decomposed water hyacinth residues [29]. It also complicates the recreational use of rivers and lakes. Water hyacinth is a serious hazard to lake transport due to its large floating mats of water hyacinth, which cause navigation difficulty [37]. Besides, this weed threatens the majority of the lake in the Dembeya, Maksegnete, and Fogera districts, because these areas of the lake's edge have access to soils that have been eroded and contain nutrients (N and P) [4]. In general, although all the social effects of the water hyacinth are the indirect effects, the problem is more significant when it affects at large conditions.

4. Management Options of Water Hyacinth

Water hyacinth is extremely difficult to eradicate once established and most management efforts are focused on minimizing economic costs and ecological change [38]. The most effective way to control water hyacinth is to keep it out of freshwater systems. This can be accomplished by educating people on how to properly dispose of unwanted water garden or aquarium plants in fresh water systems, or by cleaning boats, trailers, water sports equipment, and fishing equipment to remove all plant material before moving the equipment to another freshwater system within the lake boundaries [5]. The most common management methods used to control the expansion of water hyacinth are described as follows.

4.1. Manual Control. Water hyacinth is removed manually by uprooting weeds with hands or cutting with cutlasses [5]. It is nonselective and may destroy important fish, plant, and wildlife habitats within the target area [39]. The method is also extremely dangerous due to the presence of dangerous animals such as snakes, alligators, and crocodiles [39].

Furthermore, regrowth of the chopped weed occurs, especially if the natural enemies are not well protected during chopping [14]. Lack of knowledge about the weed's life cycle, poor storage of harvested weeds, and the spread of weed fragments to adjacent waters via disturbances and waves reduce the effectiveness of manual control in Lake Tana [21]. In earlier times, when the expansion and the invaded part of the lake were small, manual control appeared to be the best method of controlling the water hyacinth in Lake Tana [5]. According to recent survey reports, in the past 10 years, free service of a labor-based water hyacinth management system was being implemented in Lake Tana with an estimated average annual man of 250,000–300,000/day from the nearby communities via campaign [40]. Later, the government designed a strategic plan to destroy the weed by giving incentives to the workers involved in the manual control and continued the removal. Evidence shows that manual removal of water hyacinth in small areas at an early stage can be effective for short-term weed control [41]. However, the labor-based removal system was not as effective due to the vicious-circle growth of the uncollected high growth and multiplication capacity of water hyacinth (doubling within two weeks), and the entrance of high amount of nutrients from upstream areas [40].

4.2. Biological Control. Biological control is the most effective, efficient, and long-term method of large-scale removal of this weed, but it may take many years to achieve satisfactory results [14]. Insects and fungi have been studied extensively and then released to control water hyacinth [4]. However, most animals, with the exception of rabbits, do not readily consume the plant, possibly because its leaves are 95 percent water and have high tannin content [5]. In September 2016, an attempt was made to introduce a fungal species (*Rhizoctonia*, *Rhizoctonia*, *Aspergillus*, and *Tricothecum* spp.) that exhibits promising results in temporary shade in open ponds containing healthy water hyacinth plants. The fungus is only dormant in the event of rain or cold, and again became more active during hot seasons, which lasted from October 2016 to January 2017 [4]. The highest disease incidence per plant was recorded in plants inoculated with *Rhizoctonia* spp. at the end of the five-week greenhouse experiment (66.0 percent) [4]. This was significantly higher than *Tricothecum roseium* (50.7 percent) ($p = 0.05$), *Fusarium* spp (45.3 percent), and *Aspergillus niger* (42.6 percent). Based on disease severity, Admas and his colleagues reported that only *Rhizoctonia* spp. (100%) and *Fusarium* spp. (78.6 percent) showed high disease severity, causing more than 75 percent leaf death of the invasive weed. This fungal species can create necrotic disease/tissue death after 5 weeks of application, interfering with the weed species' growth and reproduction.

Furthermore, the fungi that showed promising results in the greenhouse effectively affected pods when the average temperature and humidity were 23°C and 39%, respectively [4]. However, when the season becomes hot, those fungi do not change color or become necrotic on a leaf, and they become latent during rain and cold conditions (average temperature 21°C and humidity 79 percent). As a result of this experiment, *Rhizoctonia* spp. becomes the most effective biological control method in greenhouse trials and the pond during high temperature and low humidity, but before inoculating those fungi into the lake, the impacts of those species on the lake's biodiversity should be studied using the lake's representative aquatic biodiversity.

Adult weevils are reported to be used as a biocontrol means of water hyacinth invasion. The most popular weevils, *Neochetina eichhorniae* and *Neochetina bruchi*, are common and preferred agents for biological control of water hyacinth because of their environment friendly and effectiveness in the reduction of the biomass of water hyacinth [42]. After being raised in pools, a sizable number of mature weevils can be released into the region affected by water hyacinth, where they will begin to feed on this weed [43]. *Neochetina* weevils eat only water hyacinth. Studies show that these weevils depend on the water hyacinth's root system for crucial stages of growth and feed mainly on the plant's tissues: larvae eat the inside of the plant, and adults eat the outside. The damage caused by feeding both life stages inhibits the growth and multiplication speed of the weed by slowing down its flowering process. The combined release of the two weevils results in a greater reduction in the water hyacinth's reproductive potential and vigor [44, 45]. Furthermore, the weevil *Neochetina bruchi* is regarded as a promising biocontrol agent for eliminating water hyacinth in Ethiopia [44]. Although the use of biological control agents to remove water hyacinth in Ethiopia, it is still in its early stages, yet these biocontrol agents have received ample attention at the national level [45].

4.3. Chemical Control. Herbicide control of water hyacinth is more stringent in aquatic systems than in terrestrial systems. In many countries, public opinion strongly opposes the use of chemicals in drinking water. As a result, it is not recommended at this time [5]. The main issue with chemical control is that it enriches the water by decomposing water hyacinth, and eventually, algal blooms will replace the weed [37]. Apart from environmental concerns, another constraint is the requirement to purchase simple spraying equipment to be mounted in a boat in order to apply the herbicide to bodies of water [46].

Herbicidal control with formulations containing the active ingredient glyphosate is still used in some of South Africa's larger dams and river systems to control water hyacinth. Four environmentally friendly chemical compounds, viz potassium chloride (KCl), sodium chloride (NaCl), glyphosate ($C_3H_8NO_5P$), and acetic acid 99% (CH_3COOH), at three different concentrations (15%, 20%, and 25%) were used in a foliar application [47]. The result revealed that acetic acid and glyphosate chemicals performed well in suppressing water hyacinth [47]. Among herbicides, glyphosate is the safest for use in the water bodies; however, the cost of application would prohibit it in some countries [48].

Furthermore, 2-4-D appears to be safe for fish, degrades quickly in the environment, and is significantly less expensive than glyphosate. To avoid the depletion of water oxygen availability due to the incorporation of the destroyed water hyacinth mass into the water, 2-4-D herbicides should be applied to specific infested sites rather than the entire infested area [14]. Furthermore, some effective chemicals such as dicopur 720 SL at 3 lt ha^{-1}, round up 360 SL at 5 lt ha^{-1}, or Gesapax Combi 500 FW at 6 lt ha^{-1} could be the best for small scale infestation areas [36]. Chemical control with herbicides (2-4-D or glyphosate) appears to be an economically viable option in some countries, but not in others with lower economic development [5].

4.4. Integrated Management Approach. Control of water hyacinth through an integrated management approach involves combining the mechanical, biological, and chemical methods that complement one another. Because of the rapid dispersal habit of water hyacinth, as well as practical constraints and financial costs, mechanical, biological, and chemical control measures alone are ineffective for water hyacinth control. Thus, integrated management strategies that stress the weeds over time are required for effective control, especially in established infestations [14]. To manage the abundance of water hyacinth weed sustainably, an advanced integrated weed management approach using manual, biological, and herbicides is required [49]. Water hyacinth management in Ethiopia was beyond the capabilities of local governments alone. As a result, a multidisciplinary approach, such as raising public awareness about all aspects of the weed and the use of integrated management techniques, particularly mechanical, manual, and biological control measures, should be implemented [39]. Previous studies showed that among the strategies, three applications of glyphosate, physical control, and preventive measures resulted in a reduction in the water hyacinth population, fresh weight, and number of flowers [49]. This was more effective as compared to one and two applications of glyphosate, followed by physical control along with other preventive measures and physical control along with preventive measures. When the infestation level is more severe and covers large areas, a combination of at least two management methods is required for effective result.s Therefore, an integrated water hyacinth management strategy is considered the most effective and cost-effective way of reducing and controlling the spatial and temporal invasion and infestation of water hyacinth [38].

5. Conclusion and Recommendation

Water hyacinth (*Eichhornia crassipes*) is one of the world's most invasive aquatic plant species. Because of its ability to rapidly cover entire waterways and efficient survival strategies in extreme conditions, it is arguably the most noxious aquatic weed. The main issue with this weed in Lake Tana is that it impedes water transport, blocks irrigation canals and rivers, disrupts electric power operation, increases water loss due to evapotranspiration, causes human health problems, interferes with fishing activities, and reduces aquatic biodiversity. Various management strategies such as manual/mechanical, chemical, biological, and integrated methods were used to control the weed. According to current findings, the use of biocontrol agents is the most effective, cost-effective, and long-term management strategy for water hyacinth. Except for manual weed removal, management of this invasive weed in Ethiopia is still in the trial stage. On the other hand, manual removal necessitates a large labor force and is a less effective method due to the regrowth of chopped weeds and the spread of weed fragments to adjacent waters such as the Nile Basin.

The weed is aggressive when it gets favorable conditions and seasons and covers a large area in a short period of time due to its biology and reproduction nature. As a result, we have drawn the following points:

(1) Considering the weed's biological dynamics, a multidisciplinary approach, such as raising public awareness about all aspects of the weed; implementing integrated management practices, protecting lake edges from environmental pollutants, and revising manual control methods based on the nature of the plant, should be used to manage water hyacinth in Lake Tana and the Nile Basin.

(2) Very little work has been done on the impacts of water hyacinth on the diversity of fish, livestock, crop, and other organisms in Lake Tana. This could be a new research area. Therefore, the impact of the weed in the context of biodiversity reduction should be studied.

(3) The government bodies and nongovernment organizations shall design such activities for sustainable management of the weed and to change the problem into an opportunity.

(4) Although recent studies showed the decline of the invasion, it is recommended to be aware of the weed's biology as it can cover a large area within a short time.

(5) It is also advisable to teach the surrounding communities about the utilization of water hyacinth for various products such as handicrafts for housing utilities, paper, composting, and fiber production, which can be used as a source for biogas production. These and other functions of the weed species might reduce its negative consequences and become a means of job opportunity and income generation. Therefore, sustainable monitoring and designing a new approach can change the weed problem into an opportunity for many entrepreneurial youths by providing training on processing and using water hyacinth.

Data Availability

The dataset that supports the findings of this review is included in the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest.

Authors' Contributions

Sewnet Getahun conceptualized the study and prepared and reviewed the original draft. Habtamu Kefale reviewed and restructured the manuscript.

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