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Review On Water Hyacinth Invasion In Ethiopian Major Lakes: Impacts, Management Strategies and Future Perspectives

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Abstract

Water hyacinth (Eichhornia crassipes) is one of the world's most invasive aquatic plants and is known to cause significant ecological and socio-economic effects. This senior seminar paper provided a comprehensive review of impacts and management strategies for invasive water hyacinth in major Ethiopian lakes. Water hyacinth infestations were found to obstruct waterways and inland fisheries, increase detrimental water loss through evapotranspiration, reduce water quality, damage native biodiversity and ecosystems, threaten fishing and farming livelihoods, and exacerbate public health issues. Control methods were examined, including physical removal, chemical herbicides, biological agents, and integrated techniques. While temporary relief has been achieved using manual removal and mechanical harvesting, water hyacinth populations rapidly rebound from leftover plant fragments. Similarly, chemical controls effectively kill floating mats but have concerning environmental and health impacts. Biological control utilizing host-specific insects and pathogens like weevils and fungi emerges as the most sustainable long-term management strategy, although requiring 1-3 years for establishment and optimal performance. Additionally, opportunities exist for utilizing sustainably harvested water hyacinth biomass for bioenergy production, nutrient bioremediation, and generating income through eco-entrepreneurship. Ultimately, integrated management is recommended, combining biological agents, limited herbicide use, and physical removal, together with reducing external nutrient pollution that fuels water hyacinth growth. Implementing integrated control methods through coordinated stakeholder efforts, enforcing ornamental plant trade laws, and raising public awareness can help restore invaded lakes and wetlands across Ethiopia. Further research is critically needed to evaluate integrated management strategies tailored to the environmental and socioeconomic context of affected water bodies.

Keywords; Water hyacinth; Invasive species; Ethiopian lakes; Ecological impacts; Integrated management; Control methods

Introduction

Water hyacinth (Eichhornia crassipes) is a notorious aquatic weed within the Pontederiaceae family, ranked among the world's worst top 10 invasive plants [1]. Native to the Amazon Basin, it has spread to over 50 countries across five continents since the late 1800s, propelled by its rapid growth rate, year-round flowering, and vegetative reproduction [2]. First recorded in Ethiopia in 1965, water hyacinth has since invaded many water bodies nationwide, including the Awash, Blue Nile, and Baro-Akobo River Basins [3].

Water hyacinth is an invasive aquatic weed that was first reported in Lake Tana in 2011 and by 2014 covered over 500 km2 of the lake's surface. The rapid spread is attributed to the plant's fast reproduction rate, lack of natural predators, and nutrient-rich conditions in the lake from agricultural runoff and waste disposal [4].A mature water hyacinth plant can release over 3000 seeds annually that remain viable for up to 20 years, and also reproduces vigorously through horizontal stolons and budding of daughter plants [5]. Under favourable warm, nutrient-rich, shallow water conditions, populations can double in size every 4-15 days [6]. This remarkable growth allows the weed to quickly form impenetrable floating mats over entire sections of invaded water bodies.

The proliferation of water hyacinth in Ethiopian lakes poses a significant ecological and economic challenge, threatening the integrity of aquatic ecosystems and the well-being of local communities. Despite its escalating impact, a comprehensive understanding of the multifaceted consequences, effective management strategies, and future trajectories of water hyacinth invasion in Ethiopian lakes is lacking. The lack of a synthesized and critically evaluated body of literature on this issue hinders informed decision-making and policy formulation. Therefore, there is an urgent need for a systematic literature review to address this knowledge gap, providing a comprehensive overview of the environmental and economic implications, evaluating the efficacy of existing management strategies, and proposing avenues for future research. This study aims to contribute essential insights for sustainable lake management, biodiversity conservation, and community resilience in the face of water hyacinth invasion in Ethiopian lakes.

To conduct a focused literature review on the impact and management of water hyacinth invasion in Ethiopian lakes, aiming to comprehensively analyse the consequences, assess the effectiveness of various control strategies, and evaluate the socioeconomic implications on local communities, fisheries, agriculture, and tourism.

This senior seminar paper holds substantial significance in the academic landscape. By systematically reviewing and analysing pertinent literature, this paper aims to offer a comprehensive overview of the environmental and economic consequences associated with the invasion of water hyacinth in Ethiopian lakes. The critical review of various management strategies employed in different contexts provides a nuanced understanding of their strengths and limitations. Moreover, the literature review within this paper serves to identify gaps in current

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knowledge, thereby suggesting potential avenues for future research. This contribution is integral to ongoing discussions surrounding sustainable environmental management practices. Beyond serving as an informative resource, the paper establishes a foundation for evidence-based decision-making and policy formulation. Its significance lies in its ability to inform efforts aimed at addressing the challenges posed by water hyacinth invasion. Consequently, it becomes a valuable resource for researchers, policymakers, and practitioners involved in environmental studies and management.

Methodology

In this review, an extensive literature search was conducted across prominent academic databases, including Science Direct, Springer, Wiley, and Taylor & Francis. The search utilized a combination of specific keywords such as "water and hyacinth," "weed controlling methods," "biological control method," "chemical control method," "physical control method," "integrated control method," "effect of water hyacinth," and "Impact of water hyacinth (WH)." Following the initial search, downloaded articles were scrutinized based on their quartile rankings using the Scopus database, ensuring that only articles in quartiles 1 and 2 were considered for further analysis. A systematic flowchart was employed to streamline the selection process (Figure 1).

Subsequently, 33 articles (Q1=20 & Q2=13) meeting the quartile criteria were identified and became the focus of a detailed thematic analysis. This thematic analysis aimed to extract key insights and patterns related to water hyacinth control methods and their impacts. Findings from this analysis were then synthesized to provide a coherent overview of the current state of knowledge on water hyacinth and its control strategies. Rigorous quality control measures were implemented throughout the methodology to maintain the reliability and relevance of the selected articles and subsequent thematic analysis.

Results

Impacts of water hyacinth

Obstruction of waterways and decline of inland fisheries: A major problem posed by water hyacinth infestations is the obstruction of waterways used for boat transport, transportation and migration of fish [7]. The dense masses physically block boat access and navigation, severely hindering fishing activities and the transport of people and goods across water surfaces. This essentially chokes waterways and disconnects communities, with an estimated 40-95% reduction in water flow documented in some irrigation canals in Ethiopia covered by water hyacinth [8]. Related impacts are reduced access to drinking water collection points and recreation areas along shorelines due to impenetrable hyacinth mats.

There are also substantial economic effects on the fishing industry, with fish catch declines up to 45% observed in parts of Ethiopian lakes choked by invasive water hyacinth [9]. Additionally, it has led to a major decline in fish catches by reducing fish populations, blocking access to fishing sites, and tangling nets [10]. This directly threatens the livelihoods and food security of subsistence fishing households. Underneath the mats, reduced light penetration, lower dissolved oxygen, and altered temperature profiles degrade fish habitat quality.

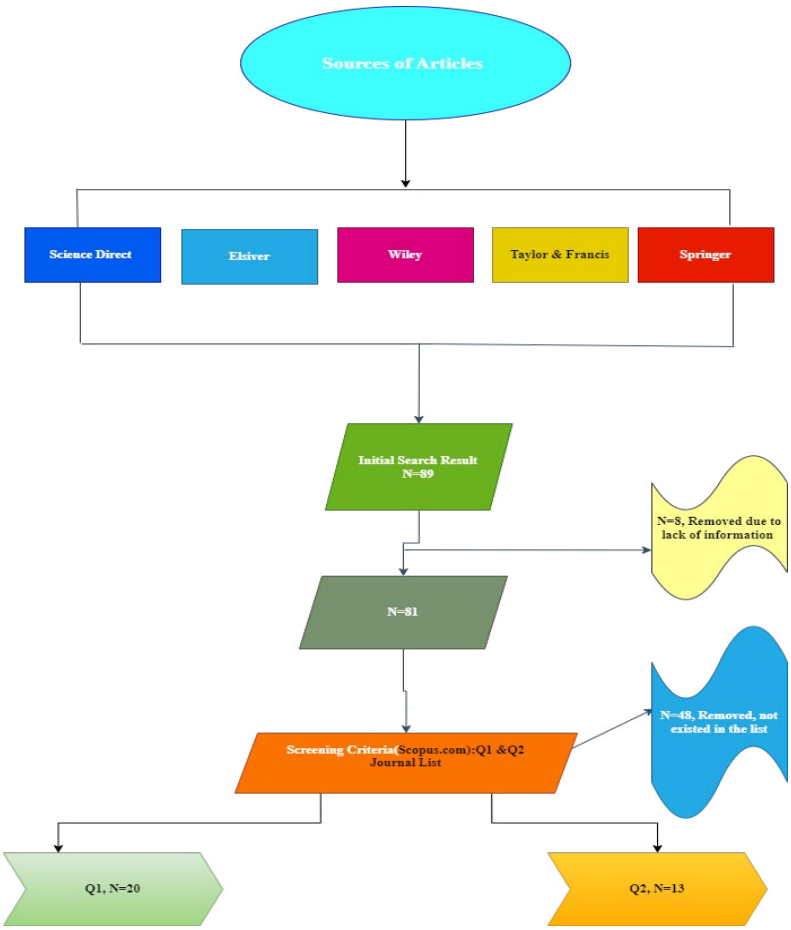

Figure 1: Flowchart for screening of the relevant articles (N=No. of articles).

Gill nets and traps also become clogged with floating vegetation. The poor rural fishing communities that depend on local lakes are among those most severely impacted by disruptions to inland fisheries caused by water hyacinth infestations.

Increased evapotranspiration and water loss: Another major concern of water hyacinth infestations is the plant's extremely high rate of transpiration, which exacerbates water loss in shallow lakes and reservoirs. Comparative studies in Ethiopia found evapotranspiration rates of 11.48 mm/day from water hyacinth plants, around 2 times higher than rates of 5.76-7.12 mm/day from native emergent macrophytes like Cyperus papyrus and Phragmites karka. At the ecosystem scale, researchers estimated that on Lake Tana alone, invasive water hyacinth increased total annual water loss by up to 52 billion m3 compared to if the lake was covered in native vegetation. For reservoirs and lakes already facing pressure from climate change and increasing human use, the additional evaporative loss from introduced water hyacinth poses a substantial threat to water security. The accelerated transpiration worsens existing struggles to meet water needs for domestic use, agriculture, and energy generation. The dense mats disrupt the lake's biodiversity by outcompeting native species, altering habitat, decreasing dissolved oxygen levels, and increasing water loss through evapotranspiration. 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.

Deterioration of water quality: Water hyacinth infestations also deteriorate water quality in a number of ways. Dense floating mats severely reduce dissolved oxygen in the water column underneath due to blocked atmospheric diffusion, decomposition of plant matter, and reduced photosynthesis. The low dissolved oxygen levels threaten growth, reproduction, and survival of fish and other aquatic organisms. Water hyacinth additionally decreases water transparency, pH, and thermal conductivity through shading effects, release of organic acids, and altered heat fluxes. The rapid spread of water hyacinth plants degrades water quality by reducing dissolved oxygen and increasing water contamination.

The study by Derseh examined declining water quality and its linkage to the spread of invasive water hyacinth in Ethiopia's Lake Tana. The researchers found high levels of total phosphorus and nitrogen entering the lake from agricultural runoff and wastewater discharge, contributing to eutrophication. This nutrient enrichment was associated with water hyacinth expansion, with an estimated 21,568-30,728 hectares susceptible to invasion. These findings align with previous studies of Ethiopian lakes demonstrating connections between land-based pollution, excessive nutrients, reduced water clarity, and proliferation of invasive aquatic weeds. For example, research on Lake Awassa traced increased nitrogen and phosphorus loading to intensive agriculture and urbanization in surrounding watersheds, which promoted algal blooms and created favourable conditions for water hyacinth growth. The Lake Tana study provides further evidence that managing nutrient inputs through improved land management practices could help control invasive and improve water quality in Ethiopian lakes.

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.

Damage to Lake Biodiversity and ecosystems: Biodiversity in Ethiopian lakes has also suffered substantial declines due to water hyacinth infestations across aquatic plant, fish, bird, and invertebrate communities. By forming extensive floating mats, the weed outcompetes and displaces native submerged, floating, and emergent aquatic plants. Documented effects of this competitive exclusion are reduced macrophyte species richness and diversity, altered wetland plant assemblages, and proliferation of invasive plants other than water hyacinth.

A recent study conducted on Lake Abaya by Mengistu also reveals a significant negative impact of the invasive water hyacinth (Eichhornia crassipes) on native macrophyte communities. The water hyacinth formed dense mats on the lake surface, hindering sunlight penetration and outcompeting submerged native plants. Infested sites experienced a 15-20% reduction in macrophyte species, along with lower abundance and diversity compared to non-infested sites. Native plants like Pistia stratiodes were displaced, and the thick hyacinth mats impeded the dispersal and germination of native plant seeds. The composition of macrophyte communities differed significantly between infested and non-infested sites, with only 45% similarity, indicating a decline in biodiversity. The invasive species altered the lake's physical and chemical environment, impacting light, temperature, oxygen, and nutrient availability for native plants. Overall, Mengistu's study emphasizes the urgent need for effective management strategies to control water hyacinth and mitigate further ecological disruptions in Lake Abaya's ecosystem.

Threats to livelihoods of fishing and farming communities: On the economic side, water hyacinth poses major threats to the livelihoods and food security of tens of thousands of Ethiopians engaged in subsistence fishing and farming around affected lakes. As previously described, dense infestations severely hamper access to open water fishing grounds, resulting in estimated annual income losses of up to $22 million around Lake Tana and its wetlands alone. For impoverished fishing households already living on the edge, such severe income declines can be financially and nutritionally catastrophic, potentially catalyzing cycles of poverty. WH has significantly reduced crop yields by covering fields and making land preparation difficult. It has also reduced grazing areas for livestock, caused livestock diseases and deaths, and increased costs for livestock owners. Econometric analysis showed the WH has significantly decreased crop production by 16.8%-25.6% and livestock holdings by 3.8%-3.9% among affected households.

Specifically, the dense mats of water hyacinth damaged croplands by up to 100% in severe cases, reduced fish catches by 46%, eliminated grazing pastures and palatable grass species, impeded water access, and disrupted transportation and tourism services that provided income for local communities (Enyew et al, 2020). 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 (278.7–475.4kg rice equivalent) and livestock production (0.083–0.114 tropical livestock unit (TLU)) of the affected household was due to water hyacinth. The expansion of water hyacinth negatively affects essential resources for local livelihoods, damaging crop fields, impeding farming activities, and diminishing fish catchability, thus increasing fishing costs. Furthermore, the weed's growth has significant implications for the national economy, disrupting hydropower generation and tourism. The dens mat cover together with the root system destructed breeding

and nursery grounds of many commercially important fishes.

Strain on irrigation and livestock grazing lands: Likewise, water hyacinth outbreaks in irrigation canals and farm drainage networks have been found to lessen water flow by up to 95%, suppressing cultivation of vital cereal crops like rice, corn, and teff that feed millions across Ethiopia. The reductions in crop yields have forced struggling rural farmers to manually clear miles of clogged canals regularly just to sustain minimal irrigation. But even with intensive labor efforts, crop productivity remains hampered by diminished water supply, creating scenarios of seasonal hunger and malnutrition. There are similar efforts by livestock owners to routinely cut pathways through rangelands and wetland grazing areas obstructed by invasive water hyacinth. Large-scale infestations essentially cripple the productivity and economic viability of Ethiopian lakeside communities that depend on diverse provisioning and regulating ecosystem services provided by these freshwater bodies. The weed has also affected livestock feed supply due to its damaging effects of various palatable grass species.

Exacerbation of public and cattle health issues: Public health issues have also arisen in communities around water bodies invaded by water hyacinth. Stagnant water and decaying vegetation trapped within the plant's tangled mats provides ideal habitat for vectors of diseases like malaria, intestinal worms, and diarrhea-causing pathogens. Documented effects around infested lakes are increased prevalence of malaria transmitted by mosquitoes that breed within floating mats, as well as higher incidence of snail-borne bilharzia that proliferates in shallow, vegetation-choked shoreline areas. Poor water quality can increase human health risks from waterborne diseases. The weed also hinders access to lake water, affecting various purposes, and disrupts livestock feed supply, leading to increased prevalence of diseases.

According to Enyew 1.43 family members were involved in the manual removal campaign of water hyacinth, with engagement levels ranging from 1 to 4 individuals. This active participation in the weeding campaign exposed local residents to health risks, as reported cases of skin rashes and other diseases were prevalent among respondents. The data revealed a high incidence of skin allergies, particularly itching, among almost all participants involved in the manual removal of the weed, underscoring the adverse health effects associated with prolonged exposure to the cool and malodorous water during the weeding activities

The decaying vegetation emits foul odors, provides breeding habitat for disease vectors like mosquitoes, and obstructs water access points for local communities. Huge water hyacinth infestation in and around the catchment of aquatic systems most importantly affects good water quality.

Foul odors emanating from decomposing plant matter also render water unacceptable for drinking, bathing, and other domestic uses. Furthermore, decaying water hyacinth supports bacterial growth and has been linked to increased cases of diarrhea and cholera around affected communities. Children and the elderly are especially vulnerable to these health risks exacerbated by water hyacinth infestations. In addition to ecological impacts, the invasive weed thus magnifies existing public health challenges across Ethiopia.

Like human health, the health of the cattle has also affected because of feeding the weed. Based on survey results, the cattle of all of herders were affected by gut bloating and continuous diarrhea due to feeding water hyacinth. Being the sole source of natural pasture by destructing the palatable grasses, the weed has increased the prevalence rate of livestock diseases and parasites (Enyew et al, 2020).

Approaches to managing water hyacinth growth: 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. The proliferation of Water Hyacinth (WH) in water bodies, fuelled by nutrient runoff from agricultural and human activities, necessitates strategic control methods (Figure 2). According to Ajithram, the initial and crucial step in WH management involves large-scale nutrient reduction solutions to minimize biomass before eradication. Dersseh on water hyacinth in Ethiopia's Lake Tana, using multi-criteria analysis, they found a high suitability for water hyacinth expansion across 58% of the lake's wetlands. Field surveys also showed water hyacinth presence increased from 10% of wetlands in 2008 to 28% by 2017. The researchers warned that without control measures, coverage could reach over 70% of suitable wetlands by 2030.

Eradication methods encompass chemical, physical (manual and mechanical removal), biological control, and integrated approaches. The selection of a suitable method is contingent upon various factors, including the size, spatial configuration, weather, water body uses, and the chronology of infestation. Recent estimates indicate water hyacinth covers up to 16% of Lake Tana's surface, although coverage fluctuates seasonally. This explosive spread has substantially degraded water quality, biodiversity, ecosystem services, and economic opportunities provided by the lake. Through a SWOT analysis of control methods, the authors argue that water hyacinth proliferation is driven primarily by eutrophication rather than invasive traits (Figure 2).

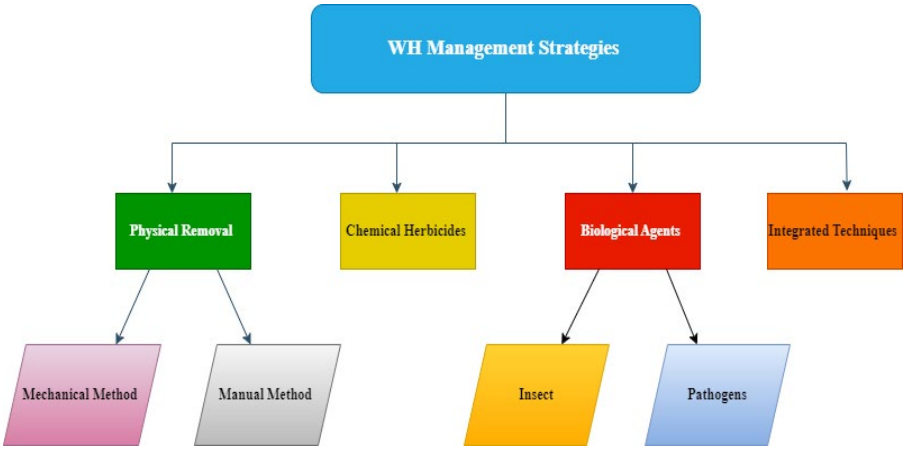

Figure 2: Water hyacinth management strategies.

Physical removal: Physical control methods consist of manual removal, carried out by humans, and mechanical removal utilizing machines like weed cutters and harvesters. However, the study found that manual removal of water hyacinth leaves isolated pools that provide ideal breeding habitats for mosquitoes, including malaria vector species like Anopheles. Anopheles and Culex larvae were significantly more abundant in water pools left after hyacinth removal compared to under the weed's dense mats. Thus, while clearing water hyacinth may improve some aspects of water quality, it also inadvertently expands mosquito development areas and could potentially increase mosquito-borne disease transmission.

The devotion of huge number of labors and investment of significant amount of money has not yet played a role in controlling weed expansion. Gezie used satellite imagery analysis to evaluate the effectiveness of a large-scale water hyacinth removal campaign on Lake Tana in Ethiopia. They found that while the one-month campaign successfully removed over 75% (1,271 ha) of water hyacinth, the plant rebounded within a year, expanding to 18% more area (2,011 ha) than before the intervention. The short-term physical removal campaigns are ineffective and unsustainable solutions.

Evidence shows that manual removal of water hyacinth in small areas at an early stage can be effective for short-term weed control. 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.

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. 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. 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. However, the implementation of this approach inadvertently shifted the attention of individuals towards the incentives rather than fostering a collective commitment to the eradication of the water hyacinth. The strategic plan, while offering rewards to incentivize manual control, unintentionally steered focus away from the primary goal of completely eliminating the weed (Figure 3).

Chemical herbicides: Controlling water hyacinth with herbicides encounters challenges in aquatic systems, particularly due to public opposition to chemical use in drinking water. The environmental impact, such as the promotion of algal blooms, and economic factors, including the high cost of glyphosate application, present hurdles. While glyphosate is considered a safer option, its expense limits its widespread use. Notably, acetic acid and glyphosate have proven effective in suppressing water hyacinth. The decision to implement herbicide control depends on the economic development of a country, making it a viable option in some regions but impractical in others with lower economic standing. This underscores the need for tailored strategies based on both environmental and economic considerations.

Chemical control, involving the use of herbicides like glyphosate, diquat, and 2,4-D, offers an immediate solution but is associated with environmental concerns . Chemical methods are recommended for small-scale infestations and emergency situations, and the integration with other control methods is advised to mitigate environmental impact (Figure 4).

Biological agents

Biological control employs organisms such as insects, bacteria, fungi, and mites to reduce WH abundance. Notably, weevils Neochetina eichhorniae and Neochetina bruchi have shown effectiveness in drastically reducing WH populations. 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. 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.

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 re-productive potential and vigor. Furthermore, the weevil Neochetina bruchi is regarded as a promising bio-control agent for eliminating water hyacinth in Ethiopia. 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.

Neochetina bruchi and N. eichhorniae demonstrated adaptability to the Rift Valley Lakes weather conditions, producing four generations per year. Neochetina bruchi showed faster development and higher reproductive capacity than N. eichhorniae. Both weevil species, through adult feeding and larval tunnelling, significantly reduced the vigour and reproduction of water hyacinth plants, leading to a substantial decrease in fresh and dry weights. The study suggests that Neochetina bruchi

Figure 3: (A) Manual method (B) Mechanical method.

Figure 4: Chemical sparing on water hyacinth weeds.

Figure 5: Two weevil species for biological method.

has promising potential as a biological control agent for water hyacinth in Ethiopian conditions based on its damage potential and population growth rates (Figure 5).

Neochetina bruchi and N. eichhorniae, evaluated for water hyacinth control in the Rift Valley of Ethiopia, demonstrated significant impacts on various hyacinth parameters. The relationship between weevil density and water hyacinth biomass followed a convex pattern. Damaged leaf area and total defoliated petioles were highest when specific combinations of weevil pairs were present. The study confirmed the weevils' high host specificity and suggested their safe release for effective water hyacinth control in the region.

Biological control using host-specific natural insect enemies and plant pathogens that damage water hyacinth tissue has arisen as a promising sustainable and ecologically sound management option. Two weevil species have been released in some Ethiopian lakes, where they feed on and bore into water hyacinth leaves and stems, stunting plant growth and reducing biomass over time. The weevils take 1-3 years to establish and fully suppress water hyacinth growth, but provide long-term control.

Additionally, certain indigenous fungal pathogens have shown effectiveness against water hyacinth in Ethiopian field trials. The fungus Alternaria eichhorniae caused total mortality within 2 weeks during a study in Lake Tana, while exhibiting host-specificity that poses minimal risks to non-target plant species. However, more testing is needed across multiple lakes to confirm these promising findings. Among the isolates, Alternaria alternata, A. tenuissima, and Alternaria spp. hold promise as possible bio-agents of water hyacinth. Laboratory study on life cycle and development of Neochetina weevils indicated the two weevils took shorter generation time in Ethiopia than in Argentina but relatively similar to Kenya and Uganda.

Challenges and limitations of physical and chemical methods

Various physical, chemical, and biological control methods have been attempted to combat the invasive spread of water hyacinth in Ethiopia's lakes, but most interventions have only achieved limited, short-term success. The rapid regrowth from any remaining plant fragments after temporary clearance efforts highlights the inefficiency and unsustainability of manual removal techniques like hand-pulling, raking and piling plants on shores over large areas. The biology and proliferation capacities of this invasive aquatic weed pose major difficulties for sustained control in Ethiopia using current individual physical methods.

Additionally, chemical control approaches face significant challenges in Ethiopia. While herbicides like 2,4-D, diquat and glyphosate are effective against water hyacinth in contained areas, they require repeated expensive applications and cause ecological damage through non-selectivity towards aquatic life. Their use is also prohibited in drinking water bodies. Furthermore, the dispersal and regrowth abilities of shredded water hyacinth after physical removal enable rapid reinfestation. The biological traits of this invasive weed pose difficulties for sustained control using individual chemical methods as well, highlighting the need for more integrated, large-scale and sustainable management approaches.

Integrated techniques: Integrated management combining multiple control methods is increasingly recognized as the most effective approach for sustainable suppression of invasive water hyacinth (WH). This strategy involves selectively applying biological, chemical, physical, and nutrient management techniques based on site-specific conditions.

Biological control using host-specific insects like weevils can provide long-term WH suppression, but takes time to establish. Rapid short-term control requires physical removal and herbicide application, but these methods are labor-intensive, expensive, and prompt regrowth. Integrating biological agents with judicious use of herbicides or mechanical removal can enhance efficacy. Critically, curtailing nutrient inputs that drive WH growth through catchment-level land management is essential.

Lack of coordination among stakeholders, proper technical expertise, and community participation has challenged integrated WH efforts to date in Ethiopia. Unintended consequences like increased mosquito breeding after weed removal also need mitigation. Prevention of further spread through trade restrictions and public education is imperative.

To sum up, sustainable WH control requires adaptive, ecosystem-based integrated strategies tailored to local contexts. Combining biological, physical, and chemical techniques with nutrient reduction offers the most cost-effective long-term management. But stakeholder collaboration, technical capacity, and community engagement are equally vital to successfully restore infested water bodies in Ethiopia.

Opportunities of water hyacinth

Water hyacinth (WH) is increasingly recognized as a versatile resource, offering promising opportunities for wastewater treatment, product development, and renewable energy. WH demonstrates a strong capacity to absorb and remove nutrients, heavy metals, and other pollutants from wastewater through phytoremediation. This highlights its potential for decentralized, low-cost wastewater treatment, particularly in rural areas.

Beyond remediation, WH biomass can be processed into diverse products, including fertilizer, animal feed, biofuels, bioplastics, and adsorbents. Cellulose extraction enables applications ranging from particle boards to brake pads. As an aquatic biomass source, WH also shows promise in renewable energy production.

Advancements in biological control methods are expanding opportunities to sustainably cultivate WH for utilization. Still, field-testing, technical refinements and further research are needed to improve productivity and commercial viability. Government support and private sector engagement can accelerate development of WH-based industries.WH is transitioning from an invasive pest to a valuable resource across diverse sectors, offering environmental and socio-

economic benefits. Leveraging its multifunctional properties through integrated utilization systems can convert WH from waste to wealth, providing sustainable solutions for many communities.

In Ethiopia, efforts are underway to develop integrated water hyacinth management systems that incorporate utilization opportunities. Pilot initiatives have shown local promise in converting harvested weed biomass into useful products like bio-briquettes, animal feed, and compost. However, most utilization activities remain experimental or small-scale community based. More widespread adoption is constrained by technical limitations, lack of infrastructure, insufficient processing capacity, limited market access and weak commercial incentives.

Discussion

The paucity of published literature meeting the criteria for inclusion in quartiles one and two presented a constraint in conducting this review. To uphold scientific rigor and ensure the studies synthesized would substantively inform decision-making, articles not classified within the top two journal quartiles were excluded. This resulted in the rejection of some potentially relevant reports. The trade-off between sensitivity and specificity is a recognized challenge in crafting systematic reviews. Future reviews could consider widening inclusion criteria, with quality assessment protocols used to critically appraise sources across a range of impact levels.

Conclusion

While substantial research has documented the threats posed by invasive water hyacinth in Ethiopia, critical knowledge gaps remain regarding long-term, sustainable control strategies tailored to local contexts. Integrated techniques that selectively combine biological agents, mechanical removal, herbicides, and nutrient reduction offer the most promise for successful suppression. However, optimal combinations and implementation models suited to different lake environments need further investigation through multi-year field studies. Research to refine biological control methods and establish locally adapted, highly impactful agents can strengthen this cornerstone approach.

Another major gap is research evaluating water hyacinth's potential for beneficial utilization in Ethiopia. Global studies highlight applications for wastewater treatment, renewable products, and bioenergy, but localized feasibility testing is lacking. Quantifying links between catchment land use, nutrient inputs, and water hyacinth proliferation is also key to guide watershed management efforts. Socioeconomic assessments focused on marginalized fishing and farming communities reliant on lakes for their livelihoods remain sparse as well.

In conclusion, addressing these research priorities underpins resilient lake socio-ecological systems that mitigate water hyacinth's negative impacts while harnessing its untapped potential. The way forward requires integrative, adaptive management centered on multi-stakeholder collaboration, impact evaluation, utilization opportunities, and local community empowerment. With continued research efforts, Ethiopians can sustainably coexist with this prolific invasive aquatic weed.

Following the findings from the review, the following outlines the identified research priority areas for water hyacinth management in Ethiopia:

Integrated management strategies: Multi-year field studies to test optimal combinations of biological, chemical, mechanical and nutrient reduction techniques based on local lake contexts

- Refine methods to enhance efficacy and sustainability of biological control agents like insects and pathogens
- Develop decision support tools to guide context-specific integrated management approaches
- Assess feasibility of local production systems for mass rearing and release of biological control agents
- Evaluate role of nutrient inputs and links to watershed land use to inform catchment management efforts

Utilization opportunities: Feasibility assessments of water hyacinth for low-cost wastewater treatment, especially in rural areas

- Techno-economic analysis of product development from water hyacinth biomass (e.g. fertilizer, animal feed, biofuels)
- Evaluate potential for renewable energy production using water hyacinth through field trials
- Research to develop sustainable harvesting systems and optimize productivity
- Assess needs for infrastructure, processing facilities and market linkages to support utilization entrepreneurs

Socioeconomic and health impacts: Quantitative assessments of economic losses for fishing, farming, ecosystems services around infested lakes

- Surveys to characterize health risks for different demographic groups from water-borne diseases
- Ethnographic studies focused on marginalized communities to inform livelihood support programs

Participatory models: Action research assessing stakeholder needs, challenges, and opportunities at local to national levels

- Develop participatory frameworks for community-driven priority setting, planning and evaluation
- Capacity building to support grassroots involvement, leadership and self-organization

In summary, targeted research efforts along these interdisciplinary themes can provide an evidentiary foundation to guide collaborative policies, community resilience programs, and adaptive management systems tailored to the Ethiopian context.

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References

1. Verma N, Khosa RL, Pathak AK (2008) Antioxidant and free radical scavenging activity of fruits of Ficus bengalensis linn. Pharmacology online 3: 206-215.
2. Chelikani P, Fita I, Loewen PC (2004) Diversity of structures and properties among catalases. Cell Mol Life Sci 61: 192-208.

3. Zamocky M, Furtmüller PG, Obinger C (2008) Evolution of catalases from bacteria to humans. Antioxid and Redox Signal 10: 1527-1548.
4. Hashida NM, Takakura Y (2009) Catalase delivery for inhibiting ROS-mediated tissue injury and tumor metastasis. Adv Drug Deliv Rev 61: 319-326.
5. Sethi RS, Schneberger D, Singh B (2013) Characterization of the lung epithelium of wild-type and TLR9 mice after single and repeated exposures to chicken barn air. Exp Toxicol Pathol 65: 357-364.
6. Arita Y, Harkness SH, Kazzaz JA, Koo HC, Joseph A, et al. (2006) Mitochondrial localization of catalase provides optimal protection from H_2O_2-induced cell death in lung epithelial cells. Am J Physiol Lung Cell Mol Physiol 290: L978-L986.
7. Raza Y, Khan A, Farooqui A, Mubarak M, Facista, et al. (2014) Oxidative DNA damage as a potential early biomarker of Helicobacter pylori associated carcinogenesis. Pathol Oncol Res 20: 839-846.
8. Schriner SE, Linford NJ, Martin GM, Treuting P, Ogburn CE, et al. (2005) Extension of murine life span by overexpression of catalase targeted to mitochondria. Science 308: 1909-1911.
9. Wang X, Phelan S, Forsman S, Kristina T, Petros E, et al. (2003) Mice with targeted mutation of peroxiredoxin 6 develop normally but are susceptible to oxidative stress. J Biol Chem 278: 25179-25190.
10. Betsuyaku T, Fuke S, Inomata T, Kaga K, Morikawa T, et al. (2013) Regulation of bronchiolar catalase in COPD depends on the duration of cigarette smoke exposure. European Respir J 42: 42-53.