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WATER HYACINTH INVASION IN THE RIFT VALLEY LAKES BASIN—AN EMERGING ENVIRONMENTAL AND SOCIO-ECONOMIC CHALLENGES: A REVIEW PAPER

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Abstract

Water hyacinth (Eichhornia crassipes) occurs almost throughout wetlands of Africa and poses serious socio-economic and environmental problems of people in riparian communities, which added constraints on the sluggish development process. This review aims to show the spatial distribution, characteristic and impacts of water hyacinth to initiate urgent policy attention and amelioration mechanisms in Rift Valley Lakes Basin (RVLB). This invasive weed has spread quickly from Amazon to many tropical and sub-tropical countries and known to cause major ecological, environmental, and socioeconomic challenges. In Ethiopia, water hyacinth was officially reported from Awash basin, Koka Lake in 1962. Then, the plant had succeeded in infesting wetlands in western and north western Ethiopia, and recently lakes of RVLB mainly Lake Ziway and Lake Abaya. Lake Ziway – the shallow freshwater ecosystem reputed for its prolific birdlife, rich fish fauna and home to hippos population, islands of ancient monasteries and engine (irrigation water source) of mechanized to smallholder farms, is a corridor of employment, industrialization, and socioeconomic development. On top of these all development led pressures, invasion of water hyacinth has conveyed competition in water demand and enhanced immense ecological and environmental challenges. Lake Abaya – the second largest lake next to Lake Tana, has recently been overrun by water hyacinth mainly sourced from the eastern side of the lake. Researchers reported that water hyacinth in Lake Abaya affects the macrophyte community composition, abundance and diversity negatively. This affirms its wider impact on Ethiopian aquatic ecosystems. A comprehensive look at the short and long term consequences of its expanding invasion within the framework of specific local environmental, ecological and societal conditions is long-overdue. Proper policy attention and interventions would reduce invasion of water hyacinth and limit water depletion to enhance water resource potential. It also reduces eutrophication, improves water ecosystem health and the livelihood of the local community and other water users.

Keywords: Abaya Lake, Ethiopia, invasive species, Rift Valley Lakes Basin, Water hyacinth, Ziway Lake

1 Introduction

Invasive species are widely accepted as one of the leading causes of biodiversity loss and can have significant effects on resource availability and can suppress the relative abundance of native species (Bhattacharya *et al*., 2015; Patel, 2012). In Ethiopia, close to 35 invasive alien plant species are posing negative impacts on native biodiversity, agricultural lands, rangelands, national parks, waterways, lakes, rivers, power dams, roadsides, urban green spaces with

great economy and social consequences (Rezene and Taye, 2014). They may also alter biological communities and ecosystem structure and processes in terms of food web structure and energy flow (Wondie, 2013).

Water hyacinth (*Eichhornia crassipes* [Mart.] Solms), is a perennial, herbaceous, free floating aquatic plant originating in the Amazon Basin, South America (Hill and Coetzee, 2008). Since the late 1800s, the plant has spread in large areas of the World (Van Driesche *et al*., 2002; Tellez *et al*., 2008). The invasive weed has spread quickly from Amazon to many tropical and subtropical countries of Latin America, the Caribbean, Africa, Southeast Asia, and the Pacific (Julien, 2001; Navarro and Phiri, 2000). This free-floating vascular plant is known to cause major ecological and socioeconomic changes. It commonly forms dense, interlocking mats due to its rapid reproductive rate and complex root structure (Mitchell, 1985). Water hyacinth reproduces both sexually and asexually. Seeds generally germinate within six months, with dry conditions promoting germination (Ueki and Oki, 1979).

According to Navarro and Phiri (2000), significant freshwater bodies, marsh and wetland areas of Africa and the Middle East have been infested by this invasive weed. It also causes serious environmental and socioeconomic problems for millions of riparian communities whose livelihoods are dependent on water bodies and it has become an additional limiting factor of development. This is because the weed affects hydropower generation, irrigation, transportation, fishing, water level, access to water supply, and rapid reproduction of diseases causing organisms like Bilharzia and Malaria (Dersseh *et al*., 2019).

In Ethiopia, this weed was officially reported in 1962 in Koka Lake of the Awash Basin (Stroud, 1994) and it has been recognized as the most damaging aquatic weed in Ethiopia since 1965 (Wondie, 2013; Tegene and Ayele, 2014; Firehun *et al*., 2014). Water hyacinth infestation in Ethiopia has been manifested on a large scale in many water bodies of the country. The introduction and rapid spread of this weed in the Awash River Basin, Abbay River Basin, Baro-Akobo Basin and Rift Valley Lakes Basins (Lake Ellen, Lake Abaya, Lake Elltoke, Lake Ziway), has created serious problems for the water ecosystem services (Stroud, 1994; Rezene, 2005; Taye *et al*., 2009, Dersseh *et al*., 2019). For Ethiopia, having an economy highly dependent on agriculture and high population growth, it is prudent to effectively manage its water resources and the services to be provided. Research and intervention gaps related to water hyacinth and other invasive species impacts on hydrology and ecosystem services are well understood so as to plan and manage intervention projects in the rift valley lakes basin. Therefore, this review aims to show the spatial distribution, characteristic and adverse impacts of water hyacinth to initiate urgent policy attention and amelioration mechanisms in Rift Valley Lakes Basin (Figure 1).

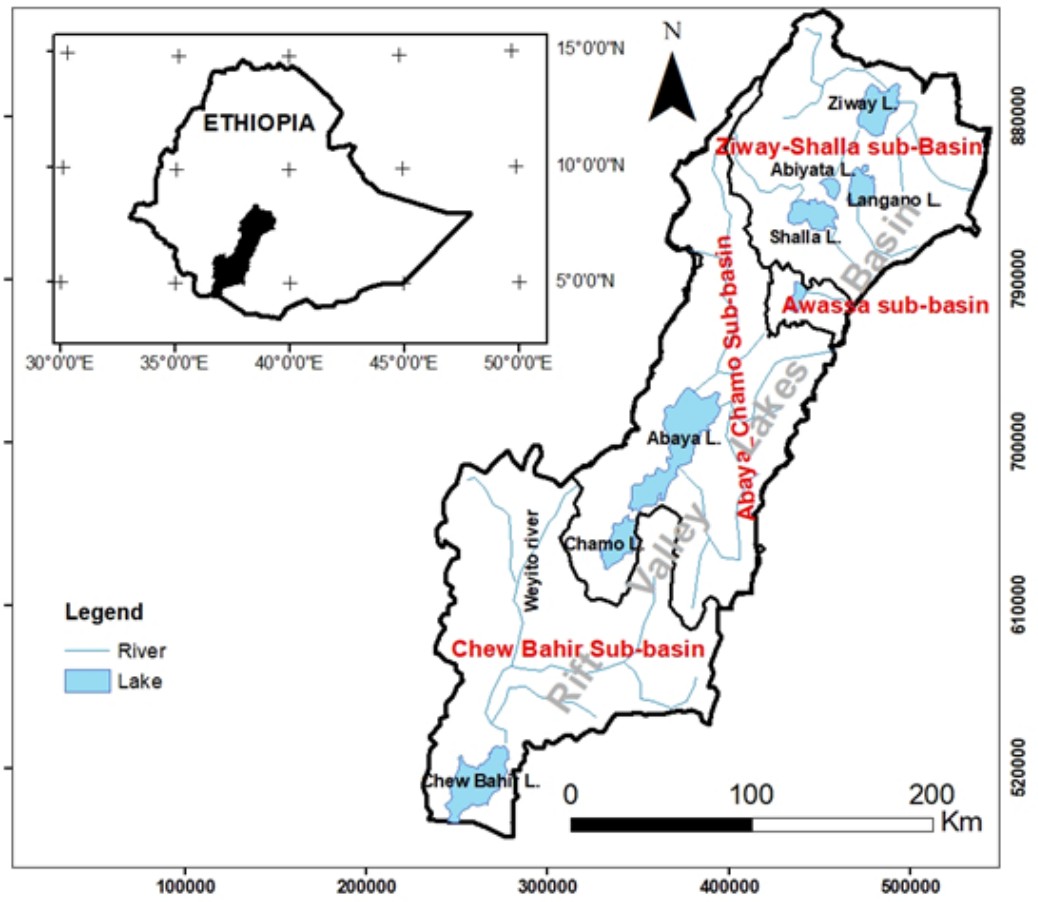

Figure 1 Rift Valley Lakes Basin (RVLB); (Source: *RVLB planning draft document*)

2 Water Hyacinth—existing situation in RVLB

Water hyacinth occurs almost throughout wet lands of Africa and poses serious socioeconomic and environmental problems on millions of people in riparian communities which added constraints on development (Howard and Matindi, 2003). Distribution modalities of water hyacinth have been different in some parts of Africa. In Egypt, Nile Delta, it has been distributed as an ornamental plant for Public gardens between the 1890s and 1900s (Gopal, 1987). In Sudan, the source of the weed was the Congo River where the infestation was since 1952. In Nigeria, the weed came from Benin (Navarro and Phiri, 2000).

In Ethiopia, the harmful water hyacinth, locally called *Emboch* had succeeded in infesting wetlands in western and north western as well as lakes of rift valley basin in Ethiopia. At that time, although authorities were notified, no subsequent action was taken. Since 1962, the plant had succeeded in infesting the whole stretch of the White Nile from Juba to Baro and Gillo Rivers in Ethiopia and Southwards up to Pibo River to Akobo. The Baro River is the main transportation route and difficulties experienced by steamers and boats have been frequently reported since the advent of water hyacinth (Rezene, 2005). Coupled with inability of communities and government authorities to respond to its infestations, connectivity among diverse water bodies during the peak rainy season has further facilitated the spread of water hyacinth (Taye, 2006).

Infestation of water hyacinth in Ethiopia has been manifested on a large scale in many water bodies of

the upper rift valley; Awash River and Lake Koka (Figure 2). Before a decade, except Lake Ellen, most Lakes of the Rift Valley Lakes Basin, such as Lake Ziway, Langano, Abiyata, Shalla, Awassa, Abaya and Chamo are proved to be free from Water hyacinth (Senayit *et al*., 2004; Rezene, 2005). However, according to RVLB Office (the then authority) assessment report (2018), showed Lake Ziway and Lake Abaya have recent been infested rapidly.

Figure 2 Koka side infestation (*Photo credit; Habtamu Temesgen, March 2021*)

Lake Ziway

Lake Ziway (or known as Batu Dembel), is the third-largest of the seven Ethiopian Rift Valley lakes and its total area is 434 sq km. It is characterized by relatively shallow freshwater ecosystem fed by the Meki and Ketar rivers and reputed for its prolific birdlife and rich fish fauna. It is also home to a small resident population of hippos. Five volcanic islands dot Lake Ziway's surface, with hiking trails, forests, and ancient monasteries to discover (Petra *et al*., 2009). Also important to mention is the irrigated agriculture which is found predominantly in the vicinity of Lake Ziway where small and medium-sized pumps draw water from the lake. Water for irrigation is abstracted by smallholder farmers, the floriculture industry, and several large investors like wineries and alfalfa. These developments are supported by the Ethiopian Government, as they are key for (youth) employment and socioeconomic development. Horticulture (vegetable-farming) has increased and irrigated agriculture now dominates even along the shore of the Lake. The growing Irrigated agriculture around Lake Ziway has conveyed competition in water demand and enhanced eutrophication (Temesgen *et al*., 2013). According to RVLBO (the then authority) assessment report (2018), more than 78 hectars of the shore of Lake ziway (in Dugda woreda) and 24 hectares in part of Ziway town are infested with this weed. Local people witnessed that water hyacinth has been recently introduced in to Lake Ziway from the neighboring Koka Lake through excavator.

Lake Ziway and its shore are of immense ecological value and provide the means of existence for millions of people. Continuous human encroachment, which enhance rapid invasion of water hyacinth (Figure 3) in this sensitive habitat is increasing environmental danger and creating harms. Intensive agriculture has caused heavy soil erosion and silting up of the Lake due to destruction of the wetland. Several species of animals and plants have already disappeared while the last wetlands and forests are still shrinking. In addition to small holder farming, the government has declared the region as an Economic Growth Corridor. The development of irrigation and other infrastructure and of export-oriented farming will lead to a further intensification of agriculture, an influx of migrants, and a deterioration of water quality. Unless mitigation measures will be enforced, these changes bear considerable risks for the downstream communities and decline of Lake Abiyata (Temesgen *et al*., 2013). The livelihoods of people living in, or along the borders of lakes and rivers depend partially or entirely on ecosystem services. Loss or degradation of the wetlands harms them directly and indirectly as ecosystems play a critical role in their daily life and in maintaining the quality of the environment.

Lake Abaya – is the second largest lake in Ethiopia with a total area of 1108.9 km2, including its islands (Sileshi, 2007). The lake is characterized by unusual reddish color, due to the presence of a large amount of iron sediment. Economically, Abaya Lake is used for fish harvesting, Roof tacking and Crocodile farming (Janko, 2014; Mengesha, 2017). The Lake has recently been overrun by water hyacinth, which is mainly sourced from the eastern side of the lake (Gelana River and Gidabo River catchments). A research conducted on Abaya Lake by Mengistu and his research group (2017) revealed that water hyacinth affects the macrophyte community composition, abundance and diversity negatively. The invasive species has reduced macrophyte abundance and diversity and in some cases changed the community to nearly monotypic flora showing its wider impact on Ethiopian aquatic ecosystems. A broad & closer, systematic and comprehensive look at the short and long term consequences of its expanding invasion within the framework of specific local environmental, ecological and societal conditions is long-overdue (Figure 3).

Figure 3 fast vanishing of water hyacinth in rift valley lakes; Lake Ziway (left), Lake Abaya (right); (*Source, Public media*)

3 Drivers of Rapid Water Hyacinth Expansion

Though the triggering factors are accumulated from activities of remotest watershed points, the rapid expansion and reproduction rate of water hyacinth is because of two major conditions: climatic and water body conditions. Temperature (which ranges from 28 $^{\circ}C$ – 30 $^{\circ}C$), sunlight shading, salinity, disturbance, eutrophication, pH, and reproduction systems are the main determinant factors for the optimum growth of water hyacinth (Gaikwad and Gavande, 2017). The most favorable conditions are quiescent water, shallow water depth ($< 6m$), bed surface covered with deposited sediment which is rich in organic matters and availability of vital elements such

as nitrogen and phosphorous in nutrients (Makhanu, 1997). Sunlight is important for photosynthesis because the nutrient uptake from the water by its root is not enough for its overall optimum growth. Optimum salinity condition for water hyacinth is $< 2\%$ salt in the water. Flooding, wave and currents are the main disturbances of the stability of the weed because high flooding, wave, and currents can flush out the weed to downstream. The favorite nutrients are nitrates, phosphates, and sulfates in dissolved form. The source of these nutrients could be polluted water by nutrients from agricultural fields, industrial zones, and residential areas. Runoff from agricultural fields contains phosphorus (P) and nitrogen (N) because of the application of chemical fertilizers and pesticides). The minimum requirement for the survival of water hyacinth is 5.5 $mg/L\,N$ and 1.66 $mg/L\,P$. For maximum growth of water hyacinth, 20 $mg/L\,N$, 3 $mg/L\,P$, 53 $mg/L\,K$ (potassium) and between 6.5 and 8.5 pH value are required (Gaikwad and Gavande, 2017; Khan and Ansari, 2005; Dersseh *et al*., 2019).

4 Environmental and Socioeconomic Impacts of Water Hyacinth

Invasion of aquatic habitats by non-native species like water hyacinth is a global environmental challenge with serious ecological, social and economic development consequences (Williamson, 1999; Villamagna and Murphy, 2010; Dersseh *et al*., 2019). They do this by altering soil and water chemistry, nutrient cycling, hydrology and disturbance regime of the infested ecosystem. Besides, they affect seedling recruitment blocking seed dispersal through their thick mat growth of stem, root and rhizome (Dersseh *et al*., 2019). As a result, they often out compete native plant species and establish a monotypic community as can be seen in Figure 1.

The social impacts include lack of clean water, increase in the prevalence of waterborne diseases, community migration, conflict among community and difficulty of getting access to water points. In some areas it can provide excessive surface area for intermediate hosts such as snails that transmit waterborne diseases such as schistosomiasis (Mengesha, 2017). The economic impacts of water hyacinth include a reduction in fish quantity and quality, blocking of waterways and impede water transportation, blocking of tunnels and turbines, and reduced hydropower generation, blockage of irrigation canals, reduction of aesthetic value of Lakes and tourism. Literatures testified that the most important environmental impacts are water quality decline, water loss due to high evapotranspiration, siltation, flooding, and aquatic life decline (Ouma *et al*., 2005; Janko, 2014; Mengesha, 2017). Water hyacinth can create an impenetrable fortress in shallow areas making it difficult to access deeper parts of water bodies for recreation, fishing, transportation etc. The mat can even hamper water flow to hydro-electric dams (Dersseh *et al*., 2019). Sedimentation, turbidity, eutrophication, deoxygenation, and proliferation of aquatic weeds are the major causes for loss of fish habitats.

Important to mention is the substantial impacts that water hyacinth have on water ecosystem service potential. It alters clarity of the water, reduction of dissolved oxygen, nitrogen, phosphorous, heavy metals, and other contaminants (Villamagna and Murphy, 2010). Water bodies infested by water hyacinth are characterized by higher turbidity, a higher level of chlorophyll, a higher level of chemical oxygen demand (COD), lower dissolved oxygen (DO), lower pH, and lower nitrates than non-infested areas (Brendonck *et al*., 2003). Hydrologic balance of water bodies is also affected by such infestation as it increases the evapotranspiration rate. Many scholars have reported a wide range of evapotranspiration rates from water hyacinth as compared to open water bodies.

5 Mitigation Framework

Water hyacinth removal campaigns have been done annually since 2012 for Lake Tana (Figure 4) and since couple of years for L. Ziway and L. Abaya. The local farmers and youths are playing a great role in these campaigns. Though, regional governments and Basin Development Authority have been working with great commitment to eradicate the water hyacinth, the expansion of the weed is far from con-

trol. The removal of the invasive weed by hand is becoming difficult and the expansion rate of the weed is extremely rapid. Thus, eradication seems to be difficult which indicates the need for integrated and sustainable management. The integration requires investigating and employing machinery, biological and chemical controls in addition to manual removal by farmers (Dersseh *et al*., 2019). Sustainable management is the focus of this mitigation framework which includes a number of intervention categories such as watershed (landscape) restoration, gulley rehabilitation, buffer zonation of water bodies, enhancing stakeholders commitment, improving harmony through reduced resources use conflict, policy issues, legal and institutional aspects etc. However, this framework is summarized under three categories: (1) *landscape functionality restoration via green-infrastructure*, (2) *stakeholder engagement*, and (3) *legal and institutional arrangements*.

Figure 4 Community taskforce trying mechanical removal from Tana Lake, (*source: public media*)

5.1 Landscape functionality restoration via green-infrastructure

Landscape restoration can have diverse targets; however, most restoration projects aim few ecosystem services with limited attention to immediate societal benefits. Restoration projects particularly in the Ethiopian Rift Valley Lakes Basin should focus on ecological restoration which eventually enhances hydrological balance and aquatic ecosystem health (Temesgen and Wu, 2018). Ecological restoration refers to the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed (Temesgen *et al*., 2013; Belete, 2017).

Ecosystem services that are potentially derived from restoration efforts are those benefits that are directly enjoyed, consumed, or used to yield human wellbeing. The notion of ecosystem qual¬ity and integrity as well as landscape functionality advocate conservation and use of soil, water, nutrients, and organic matters (collectively called "resources") within a landscape system through integration with development interventions. Many development goals are likely underpinned by the delivery of one or more ecosystem services. On the contrary, many ecosystem services depend on water and are affected by changes in water (quality) flows and gaining multiple ecosystem services through landscape restoration need to be targeted. This requires fundamental understanding

and management of the hydrologic mechanisms that underlie ecologic patterns and processes. This combined approach is termed as 'ecohydrology'. In a broader sense, targeted efforts to increase ecosystem carrying capacity and enhance the resilience and functionality of ecosystems at basin scale (Belete, 2017).

In the last few years, green infrastructure has become a popular concept to guide planning toward sustainable land use. It is a multifunctional tool which appropriates to realize objectives related to nature conservation, rural development, and sustainable agriculture and water resources use. It is an ecological technology application which has a spectrum functions that provide ecosystem services benefits of social, economy and environmental nature. The green infrastructure mainly focuses on providing multi-functional biogeochemical barriers that primarily regulate the hydrology (water cycle) and trap sediments (physical process) and nutrient cycling (chemical) that in turn enhance vegetation growth (biological process) and operates vice versa (ecohydrology) to limit eutrophication and hence aquatic weed invasions. Available literatures (Belete, 2017; Temesgen *et al*., 2018) shared the importance of multi-functionality of intervention; connectivity of upstream-downstream along the landscape continuum; restoration of ecological functionality of the landscape; and the role of hydrology and its feedback in terms of biota (dual regulation).

5.2 Stakeholder engagement

A stakeholder engagement is arguably the most important ingredients for successful project delivery and yet is often regarded as a fringe activity. Project managers depend on people to respond to the outputs and benefits that they deliver. People will only respond if they are engaged. Designing a course of action for addressing alterations to priority issues requires a thorough understanding of the stakeholders within the system boundary of the project landscape and how these stakeholders are affected by changes to the primary issues identified (Mathews *et al*., 2019). Within source-to-sea framework, Granit *et al*. (2017) suggests the following categories of stakeholders to frame stakeholders in relation to their interests in the highlighted flow (Box 1):

Box 1: Categories of stakeholders as a mapping approach

1. *Primary stakeholders* – are individuals or groups that are affected by the altered conditions, primary flows (issues), and will directly benefit from basin development strategies;
2. *Targeted stakeholders* – are actors or sectors whose practices are contributing to the altered condition and whose behaviors intervention strategies are aimed at changing;
3. *Enabling stakeholders* – are institutions providing or should provide enabling conditions for behavioral changes and benefits to occur and be sustained over time;
4. *Supporting stakeholders* – are development partners or financiers whose strategies are aligned with prevention of the altered condition;
5. *External stakeholders* – are individuals or groups outside the system boundary who share an interest in the altered condition.

Accordingly, water hyacinth and other related invasive species intervention projects in the RVLB are recommended to follow a source-to-Lake approach of stakeholders mapping and engagement (Box 1). Considering the inconsistency of stakeholders' interest and influence levels, the table below presents the diverse stakeholders categories, their role, position, interest, and concern.

Table 1 Stakeholders categories and roles for water hyacinth intervention projects in the RVLB

SN.	Categories	Role/position/interest/concern
	Primary stakeholders	
1	Farmers -particularly small-scale irrigators	Lost their irrigation site and cattle water and fodder supply due to water supply shortage and lake shore infestation as a result of invasion
2	Agri-business firms	Medium & large-scale firms may collapse as a result of water resources depletion and weed obstacles on irrigation infrastructures
3	Fishermen	Ecosystem alteration due to alien species and subsequent water resources depletion affects the livelihoods affecting the stakeholders
4	Resorts/Lodge/Hotel owners	Those hotels and resorts around the lakes and Rivers sides affected by the water resources depletion in the rift valley Lakes basin
5	Boat renters and lakeside enterprises	Owners and operators of tourist boat and other lakeside businesses that depend on the lake for attracting customers
6	Fish sellers and consumers	Small businesses of fish selling as well as the consumers
	Targeted stakeholder	
7	Agri-business firms	Most medium & large-scale firms may participate in overpumping and generally mismanagement of water resources
8	Farmers	Upstream farmers whose improper cultivation enhance nutrient laden erosion and those who cultivate lake shores
9	Firewood & charcoal traders	Retailers and wholesalers in the cities/towns are indirectly encouraging deforestation
10	Contractors in the construction industry	Transport construction materials from mountains at the upstream of the gully network, heavy trucks are adversely drive through the gully system that in turn triggers further erosion.
11	Municipalities	Whose system may loosely contribute to proper water use, allocation & management
	Enabling stakeholder	
12	Ministry of water, energy, and irrigation	Enable the community to use water and alternative energy sources
13	Basin development authority	Enable institution to implement IWRM in the basin at country level
14	Rift Valley Lakes Basin Office	Mandated institution to implement IWRM in the Rift Valley basin
15	Agriculture, land, and natural resources offices	Mandated institution to manage the natural resources in the basin
16	Environmental authority & CFEP	Mandated institution to protect the lakes and other resources from pollution
17	Municipality	Mandated for solid waste management and lakes and other parts of the rift valley basin
18	Tourism sector	Lakes and River sides used for an attraction for tourists
19	Investment bureau	Governing the investments around the water bodies (Lakes, Rivers)

Table 1 Contd.

SN.	Categories	Role/position/interest/concern
20	Universities	Higher institution (research, technology transfer, capacity building, and community services) in the rift valley
21	Alliance of friends of Lakes	Volunteer group who work in Lakes region
	Supporting stakeholder	
22	Industry parks	Social responsibility of the institutions in the water bodies
23	Hotels and resorts	Social responsibility of the Hotels and resorts in the water bodies
24	Universities	Research, technology transfer, university-industry linkage, and community service in the main Ethiopian rift valley basin
25	SIWI, IWMI	Support projects implementations to improve basin development & local communities
26	GIZ	Support projects implementations to improve basin development & local communities
	External stakeholder	
27	SIWI; GIZ; SIDA; GEF; US-AID; EU	These organizations and their network are the potential donors for source-to-lake system management of the rift valley basins

5.3 Legal and Institutional Arrangements

Analyzing the gaps in the existing governance system and the practices that are impacting the priority issues determine the success of source-to-lake* implementation. This is the way how to establish the enabling conditions that support the transition to behaviors and practices that result in the desired long-term impact (Mathews *et al*., 2019). Identifying relevant governance instruments and the institutions responsible for intervention projects implementation provides a general picture of the governance system. Further analysis of gaps in the enabling conditions, implementation barriers, conflicts or overlaps and challenges to coordination can help define where the governance system needs to be strengthened, and how much support it provides for interventions.

Instruments that influence governance range from "core" national legislation such as environment rights and obligations enshrined in the Constitution of Ethiopia or the Environmental Policy of Ethiopia, through to more specific obligations on rural land use found in regional state proclamations. Institutions can include Federal ministries and local councils. Governance institutions comprise most of the Enabling Stakeholders identified in stakeholders mapping.

Invasion trend of water hyacinth and other alien species in RVLB is the result of practices and behaviors relating to land use systems, dynamics and gaps in cultivation land management efficiency. Marginal land cultivation is also among those potential factors exacerbate erosion and transport favorite nutrients in dissolved form to water bodies and enhance weed invasion. The source of these nutrients could be polluted water by nutrients from agricultural fields, forest clearance; and also from industrial zones and residential areas. This means that instruments and institutions concerned with rural land use, agriculture, forestry, environmental protection, mining, and urban development were included within the analysis. Table 2 below provides several examples of important institutions and instruments, but is not exhaustive.

* A source-to-sea/lake system is the land area that is drained by a river system, its lakes and tributaries (the river basin), connected aquifers and downstream recipients including deltas and estuaries, coastlines and near-shore waters, the adjoining sea and continental shelf as well as the open ocean (Mathews *et al*., 2019).

Table 2 Examples of institutions and instruments

SN.	Institutions	Reason for Inclusion
1	Ministry of Agriculture & Natural Resources (MoA)	Using its hierarchical levels, the ministry supports the implementation of proclamations and regulations relating to agriculture and natural resources management. As part of its role, it administers sustainable land and watershed management and marginal land cultivation, and therefore is connected from the upper catchment to the endpoint of the system. In terms of erosion hazardous, the conversion of forest and marginal lands to agriculture as well as the increase in intensity of land uses has been a significant driver in sediment flows that increase its offsite impacts.
2	Ministry of Water, Irrigation & Energy (MoWIE)	Is a federal organization responsible for the management of water resources, water supply and sanitation, large and medium scale irrigation and electricity? The Ministry is a regulatory body, which involves the planning, development and management of resources, preparation and implementation of guidelines, strategies, polices programs, and sectoral laws and regulations. It also conducts study and research activities, provides technical support to regional water and energy bureaus.
3	Basin Development Authority (BDA)	Is housed within the MoWIE and responsible for policy development, surveys and research needed for the implementation of integrated water resource management and activities within the basins as well as developing plans for protection and sustainable uses of basins; follow-up implementation of various projects. It administers measures that should be taken against water resources depletion, pollution in the basin, working in collaboration with Regional Governments organs and other relevant bodies by setting up a forum for effective networking.
4	Commission for Forestry & Environmental Protection (CFEP)	This regional bureau is responsible for the management of the environmental impact of new activities, controlling pollution as well as monitoring the state of the environment. This Bureau is responsible for developing, conserving, and utilizing forests, which is one of the key components in the land-to-lake continuum, supporting policies and strategies from MEFCC at the Federal level. Wetlands identification, delineation, and implementation of community-based management are also done by this bureau. In terms of sediment in the sub-basin, its chief influence will be through managing activities that impact on water quality from point sources such as new development or sand-mining.
5	River Basin Councils & Basin Development Authority Proclamation (Proclamation No. 1097/2010)	This proclamation enhance decentralization of water resources planning and management functions to River Basin Organizations (RBOs) at the basin level so that most of the functions of the Federal government delegated to such a two-tier organizational set-up of RBO, Basin High Councils (BHC) and River (Lakes) Basin Authorities (RVLBA). Following this proclamation, the Council of Ministers has established by regulations the RVLBA for Abay and Awash and Rift valley lakes basin authority and basin councils.

Table 2 Contd.

SN.	Institutions	Reason for Inclusion
6	Ethiopia's Constitution of 1994	The Constitution underpins all legislation in Ethiopia and provides a basis for the development and inaction of legislation, regulation and proclamations, mainly at Federal and State levels. In addition to the rights, it also notes obligations on Governments and citizens that underpin provisions found in other Proclamations (e.g. relating to rural land use or forestry) in terms of providing or removing access to land).
7	Environmental Impact Assessment Proclamation No. 2991/2002	This Proclamation is concerned with managing activities that have an environmental impact on receiving environments but is generally focused on managing new or more significant activities and projects as opposed to managing land use. In terms of sediment, the Proclamation may be relevant for managing sediment flow from development activities across the Hawassa Sub-Basin as well as managing sand mining occurring in both lower and upper catchments.
8	Forest Development, Conservation & Utilization Proclamation No. 1065/2018	The Proclamation notes importance of Forests and Forestry to Ethiopia, and includes provisions for managing state forests, community forests, protected forests, preserved forests, private forest developers, amongst others. Given the key role of deforestation and afforestation in managing sediment flows, the implementation of this provision by regional agencies is an important part of governance.
9	E.F.D.R – Rural Land Administration & Land Use Proclamation No. 456/2005	The Proclamation provides for the rights and obligations around land use across Ethiopia, including the development of rural land use plans, use of degraded or marginal lands, and the various roles of Federal and Regional State authorities. It sets the basic conditions of rural land use across Ethiopia, and the responsibilities of various agencies and institutions. Whilst it is primarily interested in the appropriate distribution of land, it still outlines why certain lands may or may not be available for use.

6 Summary

This review aims to show the spatial distribution, characteristic and adverse impacts of water hyacinth to initiate urgent policy attention and amelioration mechanisms in Rift Valley Lakes Basin (RVLB). It also provides mitigation framework and approaches mainly for the sustainable management of the invasion. Water hyacinth has spread quickly and known to cause major ecological, environmental, and socioeconomic changes. In Ethiopia, it was officially reported from Awash basin, Koka Lake and had succeeded in infesting wetlands in Ethiopia. Recently, Lake Ziway and Lake Abaya had been under rapid infestation. On top of all development led pressures, invasion of water hyacinth has conveyed competition in water demand and enhanced immense ecological and environmental challenges in L. Ziway. Similarly, researchers reported that water hyacinth in Lake Abaya affects the macrophyte community composition, abundance and diversity negatively. This affirms its wider impact on Ethiopian aquatic ecosystems. A comprehensive look at the short and long term consequences of its expanding invasion within the framework of specific local environmental, ecological and societal conditions requires proper attention. Experiences shown that proper policy attention and interventions would reduce invasion of water

hyacinth and limit water depletion to enhance water resource potential as it reduces eutrophication, improves water ecosystem health and the livelihood of the local community and other water users. In addition to integrations that require employing machinery, biological and chemical controls and manual removal by farmers, this review also recommends a mitigation framework for sustainable management interventions such as landscape functionality restoration via green-infrastructure, stakeholder engagement, and legal and institutional arrangements.

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