

Water hyacinth (*Eichhornia crassipes* (Mart.): Land use/land cover changes and community-based management in east Shoa zone, Ethiopia

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Abstract— Water hyacinth was officially reported in Ethiopia in 1956 at Koka Dam and Awash River and it is considered as a constraint to the development of the country. Thus, this study was undertaken to determine Water hyacinth and associated land cover/use changes, and capture perceptions regarding community-based management to enhance its proper control/eradication in Lume and Boa districts, east Shoa zone, Ethiopia using integrated approach. The method of study included Water hyacinth and associated land use/cover change analyses, focus group discussions, discussions with experts at the district, zone and region levels and undertaking consultative workshop. The land use/land cover change analyses revealed increased area coverage by Water hyacinth from about 145.53 ha in 1986 to 2319.48 ha in 2015 with decline in the area of water bodies and wetlands. The annual rate of increase in the area of the weed was about 51.51% while water bodies and wetlands declined by about 0.49% and 1.16%, respectively. Of the 10 group discussions undertaken in the study districts with the communities, 9 of them reported water hyacinth to increase in terms of area coverage since its appearance in their areas which concurs the results obtained from satellite image analyses and they reported the weed to be very harmful to their livelihood. Furthermore, the nine group discussants disclosed water hyacinth to be of no use to them. Recommendations included developing comprehensive management strategies and action plans, analysis and defining roles of each stakeholder, awareness creation, training, institutional linkages, co-management and reduction of nutrient load in water bodies.

Keywords— Co-management, control/eradication, Integrated approach, Lume and Bora districts.

I. INTRODUCTION

Water hyacinth, *Eichhornia crassipes* (Martius) Solms- Laubach, is fast growing aquatic free floating fresh water plant indigenous to Brazil, Amazon basin and Ecuador region [1]. It was introduced as an ornamental species to adorn the water bodies in many countries more than a century ago for their attractive blue or purple flowers, oblong to oval glossy leaves with bulbous petioles. Later, this supposed-to-be prized plant was discovered to be an invasive species and posed serious socioeconomic and environmental problems affecting millions of people in riparian communities [2]. The sturdy plant has emerged as a major weed interfering with anthropogenic activities and is recognized as one of the top 10 worst weeds in the world [3].

In Ethiopia, water hyacinth was first reported in Lake Koka in 1956, the Awash River and since then, it has been found in different regions of Ethiopia. It is considered as a constraint to the development of the country [4] which has multifaceted problems such as obstructing electricity generation, irrigation, navigation, and fishing; increasing evapo-transpiration resulting in water loss, increase cost of crop production, providing habitat for vectors of malaria and bilharzias, harbors poisonous snakes, causing skin rashes, and hosting agents of amoebic dysentery and typhoid [4, 5] [5] and these effects have also been documented elsewhere in the world [2, 3]. The weed has infested water bodies in the two intervention districts (Lume and Bora) of the Livestock and Irrigation Value Chain for Ethiopian smallholders (LIVES) project in east Shoa zone of Oromia Region and with connection to the Awash River includes Koka Dam, lakes Ellen and Elletoke.

Local farmers in Bora district grow a number of crops for home consumption and sale mainly maize, wheat, haricot bean and tef (*Eragrostis tef*) while vegetable production (tomato, onion and others) is practiced along the shores of the lakes, mainly by private investors. Koka reservoir and lakes Ellen and Elletoke are the main water bodies in the district and are mainly used for irrigation and fishery. Koka dam is also used for recreation while the primary purpose is for hydro-electric power

generation. Koka dam and the Awash River are also found in Lume district and their use is similar to that in Bora. Similar to Bora, the livelihood of farmers in Lume is based mainly on crop production which is followed by livestock production in the form of cattle, sheep, goats, chickens, and equines although the intensity of cropping is more in Lume than in Bora district.

The economic importance of these water bodies in the study districts for many families and nationally is significant [4]. However, the extent of land covered, the spatial and temporal cover changes of water hyacinth and associated land covers/uses is not documented although there is a growing global concern about land use/cover changes which emerged due to realization that changes of the land surface influences climate and impact on ecosystem goods and services [6]. Furthermore, despite the long history of this weed in the study districts and compared to complex and diverse nature of the problem, the interventions undertaken to control the weed particularly, in the open community field, does not much with its expansion which justifies the need to assess the possibility of applying community-based management (CBM).

The objectives of this paper were to determine water hyacinth and associated land cover/use changes over the past three decades (1986 to 2015) along water hyacinth infested water bodies and capture perceptions regarding CBM, to enhance proper control/eradication of the weed in Lume and Bora districts.

II. METHODOLOGY

2.1 Description of the study area

The study was carried out along water hyacinth infested water bodies in two districts, Bora and Lume, east Shoa zone, Oromia Region, Ethiopia (Figure 1). These two LIVES intervention districts were selected because of the significance of the weed in the livelihoods of the surrounding farmers and communities beyond. Lume is located at 39°01' to 39°28' E longitude, and 8°40' to 8°84' N latitude while Bora is located at 38°75' to 39°06' E longitude, and 8°10' to 8°42' N latitude. Most of the study districts fall within the altitude range of 1,578 to 2,000 meters above sea level (masl). The study districts are located between 75 and 110 km, southeast of Addis Ababa, capital city of Ethiopia. The districts cover about 1,110.82 km² with a human population of 206, 248 (Lume = 137, 787 and Bora = 68, 461) [7]. The mean annual temperature in both districts ranges from 13 to 28°C while the mean annual rainfall is 851 mm in Lume and 500 to 800 mm in Bora. Both districts receive a bimodal rainfall; the main rain season locally known as *Ganna* extend from June to September while the short rainy season (*arfasa*) from April to May.

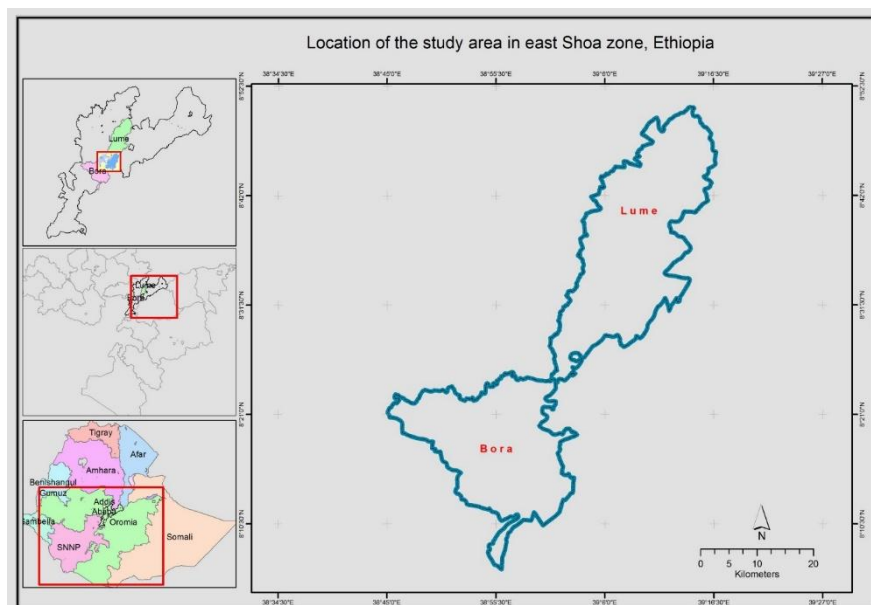


FIGURE 1. LOCATION OF THE STUDY AREA IN EAST SHOA ZONE, ETHIOPIA

2.2 Analyses of the changes in the cover of water hyacinth and associated land uses/covers

Changes in the cover of water hyacinth and associated land covers/uses were detected from the analyses of sequence of satellite imageries (Figure 2). To make the multi-temporal analysis and land cover/use types at various times extraction, cloud free Landsat TM imageries consisting of Landsat TM of 1986 and Landsat TM of 2015 (path 168 and row 54) were

analyzed to classify the land covers/uses change of the study area. All were acquired in the month of January during the dry season. Geometric correction and image enhancement were conducted using ERDAS IMAGINE 10.2 software.

Unsupervised classification of the study area was performed prior to field visit and representative points thought to represent the various land cover classes were marked using GARMIN GPS during field visit (250 GCPS). For the year 1986, false color composite was prepared using the order of 4, 3, and 2 band sequences and then different enhancements were made to increase visual interpretation of the image. In addition to GPS, digital camera was used for recording the physical features about the areas. Ground truthing activity was undertaken not only to provide information about land cover/use types, but also to provide complementary information needed to improve the final classification. Long transect and guided field walks were also made by the research team to observe, listen and to verify the status of water hyacinth and associated land cover/use classes with key informants.

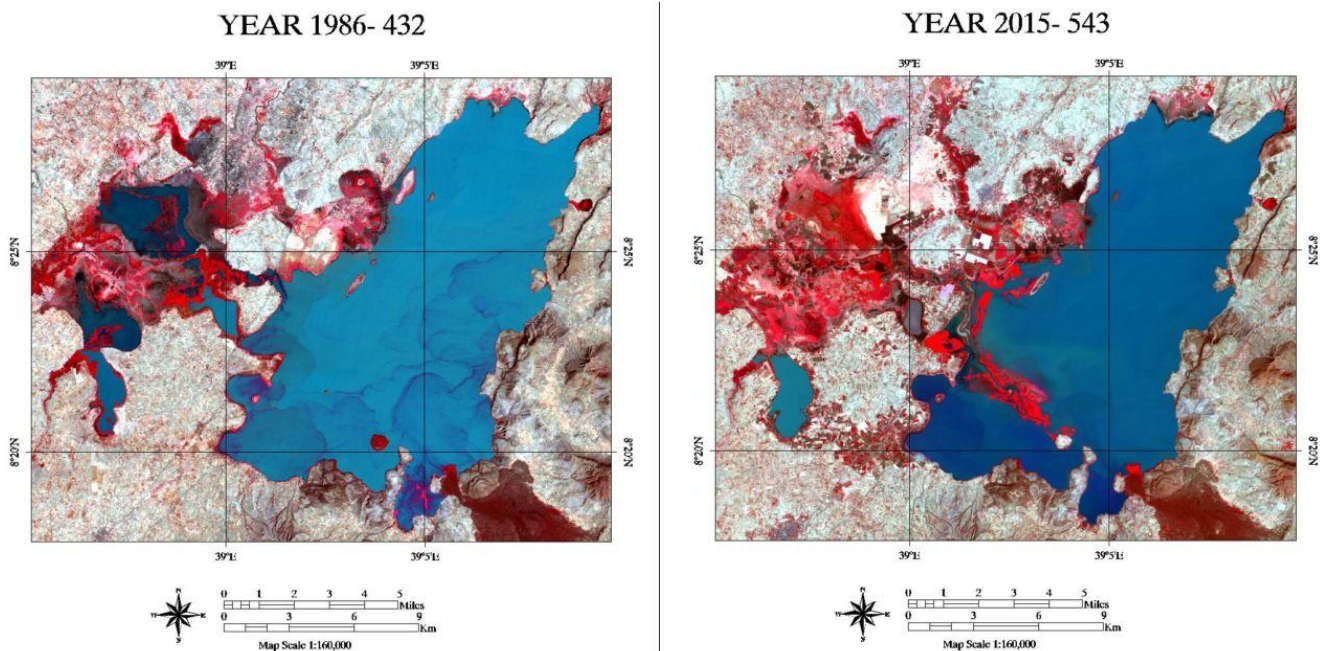


FIGURE 2. LANDSAT IMAGES OF THE STUDY AREA 1986 (LEFT) AND 2015 (RIGHT)

Based on the field check points, supervised classification approach with the maximum likelihood classifier system was applied to improve the accuracy of water hyacinth and associated land cover/use classification of the images for 1986 and 2015.

Post classification comparison was carried out for two independent images (thematic maps). Difference or change information was generated by comparing image values of one data set (TM 1986) with those of the corresponding layer of the second data set (TM 2015), conversion matrix between TM 1986 versus TM 2015 was compiled in the form of a contingency table. This conversion matrix was used to quantify land cover change in terms of pixel values, ha or percentage of area coverage. The estimation for the rate of change for the different covers/uses was computed based on the following formula:

$$\% \text{ cover change} = \frac{\text{Area } i \text{ year } x - \text{Area } i \text{ year } x+1}{\sum_{i=1}^n \text{Area } i \text{ year } x} \times 100\%$$

$$\text{Annual rate of change} = \frac{\text{Area } i \text{ year } x - \text{Area } i \text{ year } x+1}{t \text{ years}} \times 100\%$$

$$\% \text{ Annual rate of change} = \frac{\text{Area } i \text{ year } x - \text{Area } i \text{ year } x+1}{\text{Area } i \text{ year } x \times t \text{ years}} \times 100\%$$

Where $\text{Area}_{i \text{ year } x}$ = area of cover i at the first date, $\text{Area}_{i \text{ year } x+1}$ = area of cover i at the second date, $\sum_{i=1}^n \text{Area } i \text{ year } x$ = total cover area at the first and $t \text{ years}$ = period in years between the first and second scene acquisition dates.

The recognized land cover/use patterns from satellite images were exported from pixel format into a polygon and then into shape files with the help of Arc-GIS 10. The 1986 land cover/use pattern was taken as a baseline in the analyses of changes.

2.3 Community perceptions regarding land cover/use changes and CBM of water hyacinth

To gain insight into the perceptions of the communities living along the infested areas regarding land cover/use changes and relate this with the findings from imageries analyses, and to assess CBM of the weed, focus group discussions (FGDs) were held. Peasant associations (lowest administrative unit) in the infested localities were identified purposely with the staff of the district Offices of agriculture, livestock, irrigation, and peasant associations. Eleven FGDs, i.e., 6 in Bora district (Meto Aleka, Ashwa, Malima berie, Elltoke, Ellen 1 and 2), 4 in Lume (Koka Negewo, Danguge Bakale, Derera Denbela, and Adada Denbela) and one around Aba Samuel Lake (It is blamed to be the source of water hyacinth by communities) were undertaken and participants of the FGDs were 8 to 15 people from different sexes, age groups, and educational backgrounds.

2.4 Consultative meeting/workshop

The research team and the Office of agriculture of east Shoa zone organized a one day consultative meeting for researchers and development actors from across the spectrum to present and discuss research findings, identify research and development gaps, and the approach to be followed in the management of the weed. A total of 35 development and research actors participated in the meeting.

III. RESULTS AND DISCUSSION

3.1 Water hyacinth and associated land cover/use maps and their characteristics

In line with the objective of this study, five different land cover/use types were identified on 1986 and 2015 Landsat images. These are water bodies mainly found in lakes and hydroelectric dams; wetlands, area covered by water hyacinth, urban and other covers combined together. Each of the land cover is described in brief in Table 1 and shown in Figures 3 and 4. The difficult part in the analyses of the images was the identification of water hyacinth affected areas particularly on the 1986 image so we substantiated that by information we got from elders.

TABLE 1
BRIEF DESCRIPTION OF LAND-COVER TYPES IDENTIFIED ALONG THE WATER HYACINTH AFFECTED AREAS
IN THE STUDY DISTRICTS

No	Land cover-type	Brief description
1	Water body	Non-flowing, naturally enclosed bodies of water, including regulated natural lakes. The delineation of this class is based on the areal extent of water at the time the remote sensor data are acquired
2	Wetland	Are those areas where the water table is at, near, or above the land surface for a significant part of most years. They are perennial /seasonal swamps /marshy areas.
3	Water hyacinth	Areas potentially caught by water hyacinth actual or remnants of it observed. It is a perennial, herbaceous, attractive blue or purple flowers, oblong to oval glossy leaves with bulbous petioles, known as queen flower, form impenetrable mats
4	Urban	Built-up areas /town areas
5	Others	Includes cultivated land, grassland, forest land and etc.

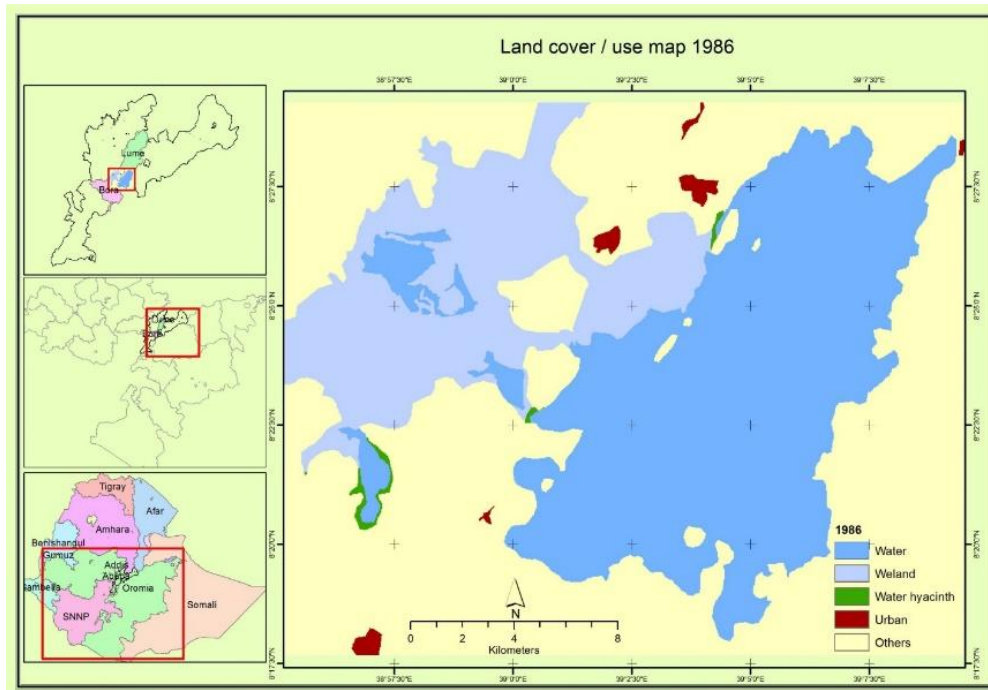


FIGURE 3. LAND COVER/USE MAP 1986

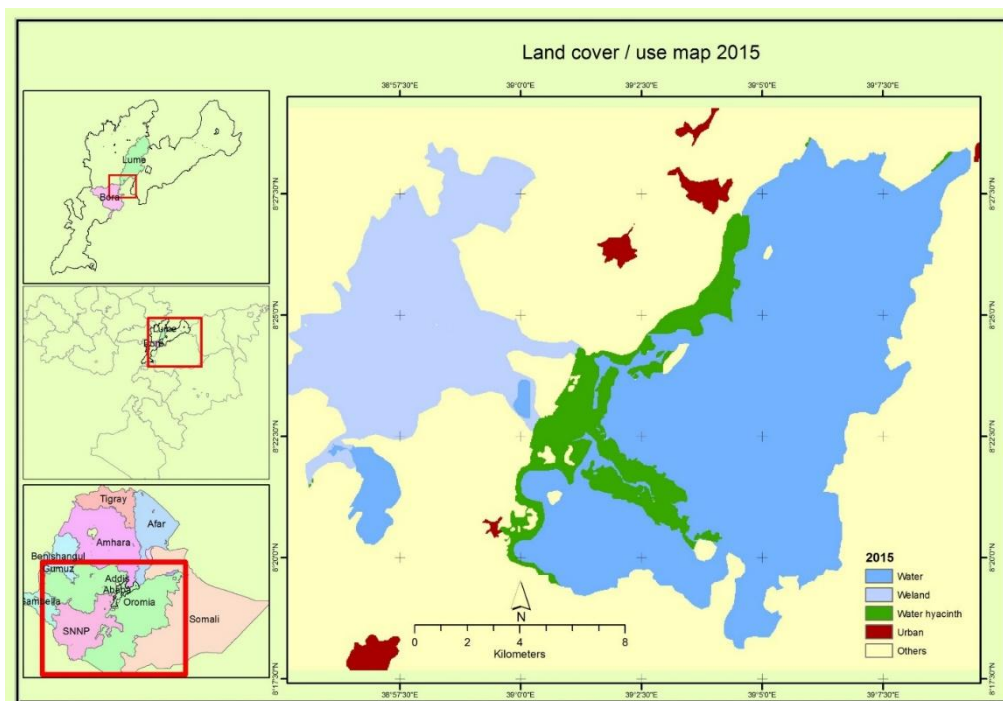


FIGURE 4. LAND COVER/USE MAP 2015

3.2 Land cover/use changes

Table 2 presents the coverage of each land cover/use class in 1986 and 2015 including the area and percentage area change between the two periods for the study area. In the periods considered for the study, our result showed, the land cover categorized as others was the largest in terms of area coverage because it encompassed different land uses/covers like cropland, grazing land, forest land, bare land and etc. Of these land covers, according to the opinion of the FGDs, the size of cultivated land and bare land has increased from time to time. As part of the Central rift Valley, east Shoa zone is well known for the presence of many lakes and a dam. According to the FGDs, the water bodies assessed were there before 30 years in their current places with some changes in their area cover with time. The wetlands which cover large shore areas provide

attractive scenery especially during the rainy season and was the third largest in terms of area coverage in both 1986 and 2015. In 1986, the area covered by town/built up area was larger than the land occupied by water hyacinth while the opposite was true for 2015 (Table 2 and Figures 3 and 4).

TABLE 2
COVER AREA, CHANGED AREA AND THE RATE OF CHANGE BETWEEN 1986 AND 2015

Land covers	Land cover (1986)		Land cover (2015)		Change area (ha)	% change	Annual rate of change (ha/year)	Average annual rate of change (%/ year)
	Cover area (ha)	% cover Coverage	Cover area (ha)	% cover Coverage				
Water body	17320.86	30.29	14842.71	25.97	-2478.15	-4.33	-85.45	-0.15
Wetland	8971.74	15.69	5943.06	10.4	-3028.68	-5.3	-104.44	-0.18
Water hyacinth	145.53	0.25	2319.48	4.06	2173.95	3.8	74.96	0.13
Town	322.47	0.56	582.39	1.02	259.92	0.45	8.96	0.02
Others	30414.87	53.2	33487.83	58.59	3072.96	5.37	105.96	0.19
Total land area	57175.47		57157.47					

As indicated in Table 2, between 1986 and 2015, water body and wetland declined by 4.33% and 5.3%, respectively while the area under water hyacinth, town and others increased. The annual rate of decline in cover was the highest for wetland (0.18%) followed by water bodies (0.15%) implying that they have lost their land for other land cover/use types. The decline in the size of wetlands and water body in the study districts goes in line with the general situation prevailing in Ethiopia [8] and globally [9] where these land covers are declining from time to time. While threats vary between regions and even within wetlands, agriculture is considered to be the most significant land use type that is replacing the wetlands [10]. The study found out that the decline in area by these land covers is because of the increase in area of water hyacinth and vegetable production using irrigation which was also witnessed by the FGDs.

Water hyacinth has a high growth rate as it can double its area coverage in only 5 days [11]. According to the opinion of nine of the FGDs, the area under water hyacinth has increased in their vicinities. Wind and water are believed to play a role for the expansion of the weed. With increase in the volume of water in the Awash River (July and August) and putting large areas under water and aided by wind, the amount of the weed coming to the different peasant associations increases and vice versa. In October, with the decrease in the volume of water and the changes in the direction of the wind, the weed is taken away and deposited mainly in Malima Berie, Elletoke and in part of Ellen peasant associations in Bora district. These sites need due consideration in controlling the expansion of the weed.

Even if the weed seems to have dried, it easily germinates and grows again if it gets water. Gopal (1987) [1] and [12] reported that water hyacinth can flower throughout the year, release more than 3,000 seeds per year, and double its population in as little as two weeks. The seeds are long-lived and can live up to 20 years [1]. While seeds may not be viable at all sites, water hyacinth commonly colonizes new areas through vegetative reproduction and propagation of horizontally growing stolons [13]. Studies have also shown that the weed favors water bodies with high-nutrient levels, such as those found downstream of agricultural or urban areas. Under such situations, water hyacinth can increase its biomass eightfold compared to water bodies that are nutrient poor [14]. Abraham (2009) [15] from his study at Aba Samuel dam near Addis Ababa reported that increase in temperature, and eutrophication by ways of increase in nutrient level and distribution to be factors contributing to water hyacinth expansion.

On the other hand, focus group discussants at Ellen PA, in Bora district, who are mainly vegetable producers disclosed that water hyacinth is disappearing from their PA particularly since the last 5 years. The main reasons for this are the increased intensity of irrigated vegetable production and the hoof action/trampling of the high livestock density coming to the area for drinking water.

The study districts are close to Addis Ababa, Adama, and Awassa and they are the major suppliers of vegetables to these cities. Many jobless youth and women came to these districts to get jobs. As these districts are economically active areas, the increase in the size of town/built up areas is an expected happening. According to Bassi et al. (2014) [10], rapid urbanization, and industrialization are some of the causes for decline in wetlands and water bodies globally.

3.3 Land covers transformation/flow

The land covers transition matrix between land cover classes in 1986 and 2015 is shown in Table 3. All land cover categories except for town/built up areas changed but with varying magnitudes and variations in magnitude of change in different land covers/uses is quite common in this type of study.

TABLE 3
CHANGE DETECTION MATRIX IN DIFFERENT LAND USE/COVER COVERAGE (HA) BETWEEN 1986 AND 2015.

Cover in 1986 (ha)	Cover in 2015 (ha)				
	Water	Wetland	Water hyacinth	Town	Others
Water	(14601.78)	727.65	1557.72	0	433.71
Wetland	49.5	(5215.41)	101.97	0	3604.86
Water hyacinth	108	0	(37.53)	0	0
Town	0	0	0	(322.47)	0
Others	83.43	0	622.26	259.92	(29449.26)

Note: The numbers in brackets indicates the cover area which remained unchanged between 1986 and 2015, while the numbers without the bracket indicate the flow of covers or covers that changed to other cover category.

Table 4 presents the detected changes in cover for the period of 1986 and 2015 deduced from the change detection matrix. For instance, a total of 3,756.33 hectares of land from the wet land area was changed to others, water hyacinth and water body areas (Table 4; Figure 6).

TABLE 4
DETECTED CHANGES IN PERCENTAGE FOR LAND COVERS/USES FOR THE PERIOD 1986 TO 2015.

Changes	1986-2015 area (ha)	% of the cover
Wetland to others	3604.86	6.30
Others to urban	259.92	0.45
Water to others	433.71	0.76
Others to water hyacinth	622.26	1.09
Water to water hyacinth	1557.72	2.72
Others to water	83.43	0.15
Water to wetland	727.65	1.27
Wetland to water hyacinth	101.97	0.18
Wetland to water	49.5	0.09
Water hyacinth to water	108	0.19

Table 5 presents a summary on changed and unchanged cover areas between 1986 and 2015. The percentage changed indicates the percentage area of a particular cover which might have changed to different covers while the percentage unchanged represents the percentage area of the original area of a particular cover which remained unchanged for a given period. From Table 5, the water body changed to different land covers by 15.7% while wetland by 41.87%. Nevertheless, water hyacinth increased by 74.21% while town/built up area by 100.0%.

TABLE 5
PERCENTAGE CHANGES OF INDIVIDUAL COVER BETWEEN 1986 AND 2015.

Cover	Unchanged	Changed	% unchanged	% changed
Water	14601.78	2719.08	84.30	15.70
Wetland	5215.41	3756.33	58.13	41.87
Water hyacinth	37.53	108	25.79	74.21
Urban	322.47	0	100.00	0
Others	29449.26	965.61	96.83	3.17

The classification accuracy assessment is shown in table 6. Of all the classes, the land cover/use category “others” exhibited low user accuracy because it combined different land cover/use types (Table 6).

TABLE 6
THE ACCURACY LEVEL OF EACH LAND COVER CATEGORY AND ERROR MATRIX SHOWING CLASSIFICATION ACCURACY

Classification	Water	Wetland	WH	Urban	Others	Total
Water	50	0	2	0	0	52
Wetland	0	32	0	0	0	32
Water hyacinth	0	0	39	0	0	39
Town	0	0	0	48	1	49
Others	0	18	9	2	49	78
Total	50	50	50	50	50	250
Classification	Reference Total	Classified total	No. of corrected	Producer Accuracy (%)	Users Accuracy (%)	
Water	50	50	50	100	96.15	
Wetland	50	32	32	64	100	
Water hyacinth	50	39	39	78	100	
Town	50	48	48	96	97.96	
Others	50	49	49	98	62.82	
Total	250	218	218			
Overall accuracy (%)					87.2 %	
Overall kappa value					0.84%	

Kappa: Estimated as (\bar{K}). It reflects the difference between actual agreement and the agreement expected by chance.

Kappa of 0.84 means there is 84% better agreement than by chance alone.

Kappa = observed accuracy – chance agreement/1- Chance agreement

Observed accuracy determined by diagonal in error matrix.

Chance agreement incorporates off-diagonal.

3.4 Community perceptions regarding land cover/use changes and community-based management

All of the FGDs in Lume and 5 of the 6 FGDs in Bora revealed water hyacinth to be of no use to them. Only one FGD in Bora, composed mainly of farmers involved in irrigated crop production (tomato, onion) around Ellen Lake, informed the plant to be useful in increasing soil fertility and used as cover plant for seedling establishment and during charcoal preparation. Although, our study did not include chemical composition analysis of the plant, studies elsewhere indicated that owing to its high alkalinity (pH>9) and potentially toxic heavy metals contents would restrict its use to flowering-plants, with no allowable application to horticulture for edible vegetables [16] which requires further investigation under our context.

The Aba Samuel Dam near Addis Ababa (capital city of Ethiopia) is commonly blamed to be the source of water hyacinth by the FGDs in the lower riparian and in literatures [e.g., 15]. The group discussants at the site, however, reported that because of the different interventions undertaken in the past 6 years (drying the water and burning the weed repeatedly), water hyacinth has almost disappeared from the area which requires further ecological study in the area.

In both districts, there is no control and/or eradication method designed by the community for managing the weed. Traditionally, communities having croplands along the water bodies pull, pile up, dry, and burn the weed for the sake of clearing their farm land but not meant for controlling the expansion of the weed. Able farmers spend about 2,500 Ethiopian birr (114.10 USD)/0.25 ha) for pulling, turning, piling up, drying, and burning the weed. Very recently (2014), the Oromia Regional government of Ethiopia, Bureau of agriculture, has started manual removal of the weed by making some payment for community members.

The group discussants also revealed the possibility of controlling/eradicating the weed from their area if the plant can be controlled from the source which is the upstream of the Awash River. Some of the interventions to be undertaken as suggested by the group discussants are:

- Organize communities to burn the plant when it has dried and regular removal of the weed
- Technical and financial support be given by government and others for the community particularly for the removal of the weed inside the water bodies as it will be difficult to remove by human labor alone
- Training, awareness creation and strong institutional linkage

According to the group discussants in both districts, there is no CBM and it is only individual effort to clear the weed from his/her piece of crop land. While the idea of CBM is well accepted in all most all the FGDs and discussions held at different levels of the offices in the region, the need for proper training on the concept, the way it can be applied, awareness creation to the communities, and institutional linkage are highly emphasized for its implementation. According to Mironga (2014) [3], the management of water hyacinth could be government based, community based or co-managed with a strong component of community participation. Mironga (2014) [3] discussed particular attention should be given to community mobilization, access to information, and coordination of community-based activities. Communities should also have a role to play in water hyacinth monitoring and the creation of early-warning systems.

Based on the results of the study, we suggest, the management of water hyacinth in the study area first be handled by co-management and based on the results be upgraded to CBM as there are many things to be fulfilled in relation to CBM.

3.5 Development and research strategy

Based on the different methods used to undertake the study, short and long term research and development strategies are outlined (Table 7).

TABLE 7
SHORT AND LONG TERM RESEARCH AND DEVELOPMENT STRATEGIES

Short term research and development strategies	Long term research and development strategies
<ul style="list-style-type: none"> • Conducting status survey to understand the magnitude of the damage it is causing • Review what we have at hand • Survey the distribution and perceptions nation wide • Categorizing infested habitats such as riverside, lakes (closed water), rivers of the infested area and demarcation • Stakeholders analysis (once identified, they should be key participants in water-hyacinth research and control. Secondly, seek to identify key stakeholders in water resources and entrust them with control of water hyacinth • Quantification of the socioeconomic and environmental consequences of water hyacinth (the exact magnitude of the social, economic, and environmental problems it causes is poorly understood in Ethiopia) 	<ul style="list-style-type: none"> • Research on policy so as to consider local, national and regional technology policy and transfer in relation to water-hyacinth control mechanisms currently in use. At each of these levels, those concerned should identify, develop, and implement policy on water-hyacinth control. • Effectiveness of available control methods —the available methods are not precisely known for their relative effectiveness in various situations. Furthermore, each one of these approaches (biological, chemical, and physical measures) has strengths as well as weaknesses. Although there is consensus on the need to combine more than one of these methods in an integrated strategy, no one has undertaken research to develop this integrated approach in Ethiopia. • Adoption of high technologies for eradication of water hyacinth • Use of biological agents • Active involvement of the stakeholders

<ul style="list-style-type: none"> • Identify alternative methods, their costs, and effectiveness of physical methods • Determine acceptable threshold levels for water hyacinth • Document the success or failure of control efforts and implementation and disseminate this information to key players in water-hyacinth control across the zone in good time. • Establishment of steering committee with responsibilities • Awareness creation and further mass mobilization of the community • Preparing community bylaws • Implementation of control strategies using manual or mechanical and chemical methods • Improving the awareness of top level policy makers 	<ul style="list-style-type: none"> • Develop mechanisms for early recognition of impending water-hyacinth infestations and problems, using local and national surveys and monitoring. Use these mechanisms to send early warnings of impending water-hyacinth infestations. More research to be conducted on the role of early-warning mechanisms in the evaluation of programs. • Conduct Environmental Impact Assessments (Because water hyacinth may contain up to 95% water, environmental consequences of the removed and decomposing weed must be evaluated and elucidated). Furthermore, where manual removal is being done particular attention must be paid to water hyacinth's association with harmful organisms, such as snails, and implications of manual removal for human health and ensure adequate protection for those handling the weed.
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IV. CONCLUSION

The results show that the extent of the problems in the study area vary from site to site requiring different approaches and use of different techniques for management of the weed, i.e., physical (manual and mechanical) and biological interventions in single or in combination depending on the nature and extent of the problem. Intensified monitoring, mitigation and management measures are needed to keep water hyacinth at unproblematic levels. For this to happen, it is very clear that the role of communities in control/eradication of water hyacinth should be increased through training, awareness creation, strengthening linkages, and supporting the communities by providing resources which are beyond their reach.

In view of the major findings of the study and the above conclusions, the following recommendations can be drawn:

- It is critical to develop comprehensive management strategies and action plans. A multidisciplinary approach should be designed, which ensures that the highest political and administrative levels recognize the potential seriousness of the weed. Solicit the good will of politicians to support water hyacinth control
- Plans should also state clearly the role of each government department, stakeholders, municipal councils and local community involved in the fight against water hyacinth
- Methods for water hyacinth control should include reduction of nutrient load in the water bodies through treatment of waters flowing from sewage works, urban wastes and factories. Changing land use practices in the riparian communities through watershed management will help reduce agricultural runoff as a mechanism for controlling the proliferation of water hyacinth
- Early detection and monitoring are critical for the management of water hyacinth, as successful eradication or containment is normally only possible when infestations are small. This is also essential to avoid re-establishment and further spread from the soil seed bank
- Education programs particularly public education and establishment of information center need to be undertaken

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