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Seasonal variation of Water Hyacinth in Lake Koka, a part of Awash Basin and Lake Ziway (Ethiopia)

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Abstract
Water hyacinth is an invasive weed that poses a significant threat to the ecosystem and human well-being in Ethiopia. It has invaded Lake Koka and Lake Ziway, substantially decreasing water availability and sustainable water biodiversity in Ethiopian lakes. Although the threats and effects of this weed are well-documented, its distribution is not well understood. Therefore, the main objective of this study was to predict the coverage areas of the water hyacinth over the surface of the lake using the geographical information system (GIS) - based multi-criteria evaluation technique (Sentinel-2 image). Field collections were conducted in Lake Koka, a part of the Awash Basin, and Lake Ziway during the wet and dry seasons of 2020. During sample collection, the coverage of water bodies was inspected for water hyacinth infestation, and GPS readings were taken at various points while in the water. Multivariate statistical classifier was used to classify various land cover features. This classifier was then used to map the spatial distribution of water hyacinth and determine the accuracy of the classification. The results of the study found that during the dry season, the area of Lake Koka covered by water hyacinth ranged from 1455.39 ha (3.87%) of the lake area to about 4678.06 he (12.44% of the lake area) during the rainy season. Similarly, in Lake Ziway, the area covered by water hyacinth ranged from 6526.30 (10.014%) of the lake area during the dry season to about 7424.05 hectares (11.39% of the lake area) during the rainy season. According to the study, during the rainy season, a considerable portion of Lake Koka and Lake Ziway becomes covered by water hyacinth, which is detrimental to water biodiversity and socioeconomic development. The study revealed that there was a decrease in the area covered by water hyacinths in agricultural land, water, and bare land. To prevent these adverse effects, it is recommended to restore healthy land use and regularly assess the growth of the weeds.

Keywords: Distribution, dry season, gis, sentinel-2 images, spatial variation, water hyacinth, wet season

1. Introduction

Water hyacinth (*Pontederia crassipes*) is one of the world's most prevalent invasive aquatic floating freshwater plants Originated from South America and is indigenous to Brazil, the Amazon basin, and Ecuador region (Gopal, 1987) [1]. It is a free-floating aquatic plant that is known to cause significant ecological and socio-economic changes (Center, 1994) [2]. Due to its lack of natural enemies, this weed spreads rapidly and forms thick mats in slow-moving waters (Edwards and Musil, 1975) [3] degrading aquatic ecosystems and limiting their use.

The presence of dense and impenetrable mats hinders access to water, which has negative impacts on fisheries, commercial activities, irrigation canal operations, navigation, transportation, hydroelectric programs, and tourism (Navarro and Phiri, 2000) [5]. As the presence of water hyacinths decrease their impact on benzoid diversity and animal disease transmission, they also contribute to the increase in vectors of human and other diseases like malaria that interfere with pesticide application (Harley *et al*., 1996) [8].

Water hyacinth was originally introduced to Africa from South America in the early 1900s (Mitchell, 1985; Gopal, 1987) [9, 1]. Since the 1950s, it has become a problematic weed in Southern Africa, the Congo basin, and the Upper Nile (Rzoska, 1974; Denny, 1984) [10, 11]. In East Africa, the weed was first observed in Uganda, Tanzania, and Kenya in 1987 (Ogwang and Molo, 1999) [12].

In Ethiopia, this weed was first reported in 1956 in Koka Lake and the Awash River. At that time, even though the infestation changed to small, the worried government was notified of its capacity-poor consequences on those water bodies and the network at large.

It is taken into consideration as a constraint to the improvement of the country (Senayit R *et al*., 2004) [13] which has multifaceted issues consisting of obstructing energy generation, irrigation, navigation, and fishing; increasing evapotranspiration resulting in water loss, growing the value of crop production, imparting habitat for vectors of malaria and bilharzias, harbors toxic snakes, inflicting pores and skin rashes, and web website hosting marketers of amoebic dysentery and typhoid (Senayit R *et al*., 2004, Taye Tessema *et al*., 2009) [13, 14] and those consequences have additionally been documented some other place in the world (Patel, 2012) [15]. The weed has infested water bodies' East Shoa Zone of the Oromia Region and with connection to the Awash River consists of Koka Lakes, Lake Ellen, Elltoke, and Lake Ziway. However, for eradication of the weed as opposed to bodily way no next action was taken.

In 1996, the Wonji-Shoa sugar estate was flooded by the Awash River, causing water hyacinth to take over the reservoirs, irrigation, and drainage structures (Firehun Yirefu *et al*., 2007) [16]. The severity of the situation was realized in 2005 and a management strategy was launched to control the weed nationally. According to Firehun Yirefu *et al*. (2007), various methods including manual, mechanical, biological, and chemical measures were used in the management application. However, the successful implementation was seen in the manual, chemical, and mechanical methods. Although some infested areas were treated with these programs (Dula A *et al*., 2008, Taye Tessema *et al*., 2009) [17, 14], the water hyacinth continues to spread in the Rift Valley of Ethiopia.

The water bodies within the study areas are of great economic significance to both households and the nation as a whole (Senayit R *et al*., 2004) [13]. However, the extent of land coverage, in addition to the spatial and temporal modifications in water hyacinth and its associated land covers/uses, has no longer been documented. This is no matter the developing international difficulty approximately modifications in land use/cover, which has emerged because of the realization that changes in land surface have an impact on weather and surrounding items and services (Lambin, 2003) [18]. Additionally, no matter the lengthy recordsof this weed in the examine areas, and its complicated and various nature, interventions undertaken to manipulate it, specially in the community field, have now no longer been powerful in stopping its expansion. This justifies the need to assess the possibility of applying community-based management (CBM).

The weed causes extreme socioeconomic effects around Lake Koka and Lake Ziway. The socioeconomic activities, whose livelihoods are dependently on the Lake, are laid low by the water hyacinth invasion. Fishing is turning into difficult for the fishermen and the transportation of small boats presents a venture because of the thick mat formation of the weed. Animal grazing land and agricultural land are blanketed by invasive weeds, affecting agricultural practices (Wassie Anteneh *et al.*, 2015, Ketema, 2013, & Tewabe, 2015) [19, 20, 21]. Because the water hyacinth is a recent occurrence in Ethiopia, there are limited studies available on the subject. Only a few research articles exist, such as those (Wassie Anteneh *et al.*, 2015, Ketema, 2013, & Tewabe, 2015) [19, 20, 21] that acknowledge the challenges in controlling the water hyacinth, as there is still a lack of understanding regarding its origins, growth, and distribution.

To better understand this issue, different types of satellite imagery have been used, including SPOT (Venugopal, 1998) [22], MODIS (Fusilli *et al*., 2013) [23], and Landsat TM, ETM+ or MSS (Dube *et al*., 2017) [24]. While these have been successful in detecting and mapping submerged plants, poor spatial resolution has resulted in mixed pixels and slightly lower accuracy. Venugopal (1998) [22], showed the usefulness of satellite images, e.g. SPOT in monitoring the infestation of water hyacinth in Bangalore, India. Comprehensive information on the spatial distribution of water hyacinths and their annual and seasonal variability is critical in managing water resources (Molinos *et al*., 2015) [25]. So far, Sentinel-2 MSI data has managed to provide valuable insights into grass mapping (Shoko and Mutanga, 2017) [26], crop monitoring (Campos-Taberner *et al*., 2016) [27], as well as agricultural mapping (Wang *et al*., 2013) [28]. Water hyacinth has become a major invasive alien weed, particularly in Lake Koka, a part of Awash Basin and around Lake Ziway. Accurate estimates of its distribution and abundance are needed to evaluate the severity of the problem. To analyze its dynamics, the study used Sentinel-2 images, ground points, and the Random Forest (RF) classification algorithm in Google Earth Engine and TerrSet2020 for change analysis.

2. Materials and Methods

2.1 Study area

The research was carried out at Lake Koka, which is a part of the Awash River Basin lake group located in the Oromia Regional State, East Shoa Zone (between Lume and Bora Woredas), and Arsi Zone (Dodota Woreda) (Abebe Cheffo, 2013) [29]. The Lake has 255 km2 areas, a maximum depth of 14 meters, a minimum depth of 9 meters, a maximum length of 20 kilometers, a maximum width of 15 kilometers, a shoreline of 195-205 kilometers, and a water temperature of 20 °C. According to Hadgembes Tesfay (2007) [30], it is located between 802´ to 8026´N latitude, 390 to 39010´E longitude, and an altitude elevation of 1660 meters above sea level. Lake Ziway is another study area which is a shallow freshwater lake found in the northern part of the Ethiopian Rift Valley and is located at 08001'N and 38047'E and about 163 km south of Addis Ababa, in Oromia Region East Shewa Zone. It has a mean annual precipitation between 650 and 1200 mm and a mean annual temperature between 15 and 25 °C (Pagad *et al*., 2016) [31].

2.2 Methodology

2.2.1 Sample collection for geographic and seasonal coverage of water hyacinth

Field collection was conducted during the wet and dry season of 2020. In these surveys, Lake Koka, a part of Awash Basin and Lake Ziway were examined for possible infestation by water hyacinths. Survey sites were selected based on the presence of water hyacinths and their accessibility. During sample collection water bodies' coverage must be known and was inspected for water hyacinth infestation. The survey team collected samples and took GPS readings to identify and record infested water bodies. Remote sensing was used to assess the spread of water hyacinths, and the geographic coordinates were transferred to a GIS environment to generate a map of the infestation severity. Sentinel-2 images were also used to estimate the coverage area. It's interesting to note that the survey team collected essential water frame and river community form documents from the Central Statistics Agency of Ethiopia while mapping the severity of the water hyacinth.

2.2.2 Data Analysis

The methods of analysis for this study consist of four main steps: data collection and preprocessing, image classification, accuracy assessment, and change analysis. Each step is defined in the element below.

1. Data collection and preprocessing: The data used for this study include Sentinel-2 images, ground points, and SRTM DEM. Sentinel-2 images with 10 m spatial resolution and nine spectral bands (B2, B3, B4, B5, B6, B7, B8, B11, B12) covering Koka Lake for the dry season (25/03/2020-10/04/2020) and wet season (05/10/2020-10/10/2020) were filtered from the Copernicus Open Access Hub. The technique used in this case was chosen based on its reported performance as per the studies conducted by Sepuru and Dube (2018) and Thamaga and Dube (2018) [32] [33]. This technique estimates the atmospheric path radiance by opting for the darkest pixel in the scene and assumes that the atmosphere is homogenous across the entire scene, as explained by Matthews *et al*. (2010) [34]. Once the atmospheric effects were accounted for, the images were transformed from radiance to reflectance values. The images were preprocessed in Google Earth Engine to apply cloud masking, atmospheric correction, and clipping to the study area (Koka). Ground points representing water hyacinth and other land cover types (Water, Bare soils, and Agriculture) were collected by GPS in both seasons and uploaded to Google Earth Engine as feature collections. Elevation, slope, and aspect data are derived from the Shuttle Radar Topography Mission (SRTM) digital elevation model (DEM) with 30 m resolution. Indices such as NDVI, NDWI, and SAVI are calculated from the Sentinel-2 bands using Google Earth Engine. In the case of Ziway, the same steps were followed but in the image collection the dates were for the dry season (25/03/2020-10/04/2020) and wet season (01/10/2020-10/10/2020) were filtered from the Copernicus Open Access Hub. The cover classes were mainly four (Agriculture, Built Area, Water, and Water Hyacinth Risked).

Table 1: Ground points used for classifications

No.	Lake Koka					Lake Ziway				
	LULC Classes	Dry	Test point	Wet	Test point	LULC Classes	Dry	Test point	Wet	Test point
1	Agriculture	106	52	109	52	Agriculture	76	22	95	42
2	Bare-soils	52	18	34	16	Built Area	30	9	35	10
3	Water	53	21	53	18	Water	72	31	80	32
4	Water Hya.	58	32	60	41	WH Risked**	71	35	84	21

2. Image classification: The RF (Random Forest) classification algorithm is applied to the Sentinel-2 bands in Google Earth Engine to classify the pixels into four classes: Water hyacinth, Water, Agriculture, and Bare soil. RF is a supervised machine learning technique that uses multiple decision trees to generate a final prediction based on the majority vote of the trees. RF is chosen for its robustness, accuracy, and ability to handle high-dimensional data. The ground points are used as training and testing samples to train and evaluate the RF classifier. The classification results are exported as raster images for further analysis (Seasonal cover change dynamics in TerrSett 2020).

3. Accuracy assessment: The accuracy of the classification results is assessed using confusion matrices, overall accuracy, producer's accuracy, a user's accuracy, and kappa coefficient. These metrics are calculated in Google Earth Engine using the testing samples that were not used for training the RF classifier by an approach of 70% to 30% ratio i.e., seventy percent for training the classifier and 30% for testing. The accuracy assessment is performed for both seasons independently to compare the performance of the classifier.

4. Change analysis: The change analysis was performed using TerrSet2020, software for geospatial monitoring and modeling. The classified images for both seasons are imported to TerrSet2020 and converted to IDRISI raster format. The change analysis module is used to generate a change image that shows the areas of increase, decrease, or no change in water hyacinth coverage from dry to wet season. The change image is also used to calculate the percentage of change in the water hyacinth area between the two seasons.

3. Results and Discussion

3.1 Spatial Extent and Distribution of Water Hyacinth in Lake Koka, a part of Awash Basin

The surveys were conducted during both the dry and wet seasons of 2020, to determine the distribution and abundance of water hyacinth in Lake Koka, which is located in the Awash Basin, as well as Lake Ziway. The current distribution of water hyacinths on Lake Koka, which is a part of the Awash Basin, was depicted on a map by analyzing historical data, satellite images, and conducting surveys in the field. Remote sensing technologies and their derivatives have had a crucial impact on the identification, mapping, and tracking of water hyacinths in water sources. Different sensors have been utilized to evaluate a range of spectral bands and vegetation indices to map the spatial arrangement of water hyacinths (Cheruiyot *et al*., 2014; Cho *et al*., 2008; Dube *et al*., 2017b) [35, 36, 37]. During the dry season, the water hyacinth covered approximately 1455.39 hectares, which accounted for 3.87% of the Lake Koka. However, during the rainy season, the coverage expanded to around 4678.06 hectares, making up 12.44% of the lake area. The area of the water hyacinth present on the lake's surface was determined by utilizing ILWIS (Integrated Land and Water Information System) and analyzing the classification outcome. By the integration of Different Classification Approaches the Koka Lake; agriculture, bare soil, water Hyacinth, and water body are summarized in Table 2. The classes were defined specifically to the area. Seasonally variability of water hyacinth coverage was described in the Table 2. Worqlul *et al*. (2020) [38] used high-resolution Planet Scope satellite images to map the spatiotemporal dynamics of water hyacinth in Lake Tana from August 2017 to July 2018. They found that water hyacinth coverage increased from 112.1 ha to 1512 ha, and that lake level and night-time water temperature were strongly correlated with water hyacinth spatial coverage. Dersseh Melesse *et al*. (2020a) [39] used Sentinel-2A/B satellite images to monitor the water quality and water hyacinth distribution in Lake Tana from 2015 to 2019. They found that water hyacinth covered 8.2% of the lake area in 2019, and that water hyacinth density was positively correlated with chlorophyll-a concentration and turbidity.

Table 2: Koka Lake LULC Analysis for Dry and Wet Seasons of year 2020

Number	LULC Classes	Area in hectares	
		Dry	Wet
1	Agriculture	17552.33	13868.16
2	Bare soils	4310.39	1584.39
3	Water	14266.26	17453.76
4	Water Hyacinth	1455.39	4678.06

The table presents the land use and land cover (LULC) analysis for Koka Lake in Ethiopia for the dry and wet seasons of the year 2020. The LULC classes are agriculture, bare soils, water, and water hyacinth, and their areas are in hectares. The table shows that the area of agriculture and bare soils shrink from dry to wet season, while the area of water and water hyacinth expand. This indicates that the Lake undergoes seasonal changes in water level and vegetation cover. In various regions across the globe, it has been documented that both natural and human-induced elements like chemicals, floods, and destruction of wetlands have an impact on typical environments, especially during the wet season favoring invasive species dominance by water hyacinth (Firehun Yirefu *et al*., 2007) [16]. The area of agriculture decreased by 20.97% from17, 552.33 hectares in the dry season to 13, 868.16 hectares in the wet season. This may be due to the flooding of agricultural lands by the rising water level or the harvesting of crops by farmers before the onset of the wet season. The area of bare soils decreases by 63.24% from 4310.39 hectares in the dry season to 1584.39 hectares in the wet season. This may be due to the erosion of soil by runoff or the submergence of soil by water. The area of water increases by 22.31% from 14266.26 hectares in the dry season to 17453.76 hectares in the wet season. This may be due to the increased rainfall and inflow of water from tributaries during the wet season.

The area of water hyacinth increases by 221.55% from 1455.39 hectares in the dry season to 4678.06 hectares in the wet season. This is due to the favorable conditions for the growth and spread of this invasive aquatic plant, such as high water level, high nutrient concentration, and low water flow. These outcomes validate the earlier findings made by Worqlul *et al*. (2020) [38], who find that the greatest extent of water hyacinth growth occurred during the last part of the wet season, specifically in October and November 2017. However, according to Dersseh Melesse *et al*. (2020) [39] the top coverage changed slightly from October 2016 and 2017 to December 2018 and 2019. Under favorable conditions, water hyacinths can double their area coverage in just 5 days, as stated by Ntiba *et al*. (2001) [40]. Wind and water also influence the spread of the weed during wet season. When the water level rises and floods large areas in the wet season, the wind carries the weed to different locations. When the water level drops and the wind changes direction in the dry season, the weed is removed and deposited elsewhere. These sites require special attention to control the weed. Water hyacinth grows faster in the wet than in the dry season (Bock, 1969) [41]. During the wet season, there is an increase in temperature, precipitation, runoff, and nutrient loads from nearby farms. This leads to eutrophication, which in turn speeds up the growth of the weed. This is supported by research conducted by (Mangas-Ramírez and Elias-Gutierrez, 2010; Kriticos and Brunel, 2016) [42, 43].

The presence of water hyacinth varies significantly depending on the specific location and season. A recent study on Lake Koka and Lake Ziway unveiled an increase in the presence of water hyacinths, leading to a decrease in the amount of open water in the area. Although the study found that water hyacinth coverage alternated between increasing and decreasing over different seasons, it also showed that during dry seasons, people removed a significant amount of the water hyacinth. This was also studied on water hyacinth coverage in northern Bangalore, which showed rapid growth in biomass levels from 1988-2001, utilized images from the Indian Remote Sensing Satellites LISS-II and III to make these observations (Verma *et al*., 2003) [44]. However, the biomass level returned to previous levels within a month, highlighting the difficulty of managing its growth. This suggests that current management practices are inadequate.

Table 3: Koka Lake Water Hyacinth Change Analysis 2020 Dry to Wet Season dynamics

No.	Changes	Area- Hectares
1	Bare soils to Agriculture	620.36
2	Agriculture to Bare soils	998.86
3	Agriculture to Water	1162.60
4	Bare soils to Water	1628.93
5	Water Hyacinth to Water	395.97
6	Agriculture to Water Hyacinth	2251.46
7	Bare soils to Water Hyacinth	1507.15

Table 3 shows the water hyacinth change analysis for the Koka Lake in Ethiopia comparing the dry season to the wet season in 2020. The table lists the area in hectares of different land use and land cover (LULC) classes that changed to another LULC class, and the type of change that occurred. The table reveals that the most common change was from agriculture and bare soils to water and water hyacinth, indicating that these lands were either flooded or colonized by the invasive plant. The total area of these changes was 6550.14 hectares, which made up 76.47% of the overall area of changes (8565.33 ha).

The area of bare soils changed to agriculture was 620.36 hectares, which was the smallest change in the table. This may be due to the cultivation of crops by farmers on previously barren lands. The area of agriculture converted to bare soils was 998.86 hectares, which was the second smallest change in the table. This may be due to the erosion of soil by runoff or the abandonment of agricultural lands by farmers. However, in this particular region, the majority of farmers cultivate vegetables. It has been revealed that water hyacinth and other types of vegetables are vanishing from their fields due to the primary reason of excessive livestock trampling the area, especially during the dry season, while seeking water to drink. The area of agriculture converted to water was 1162.60 hectares, which was the third smallest change in the table. This may be due to the submergence of agricultural lands by water as the water level rose. The area of bare soils converted to water was 1628.93 hectares, which was the fourth smallest change in the table. This may be due to the submergence of bare soils by water as the water level rose. The area of water hyacinth converted to water was 395.97 hectares, which was the fifth smallest change in the table. This may be due to the removal or decay of water hyacinth by natural or human factors.

The area of bare soils converted to water hyacinth was 1507.15 hectares, which was the second largest change in the table. This may be due to the invasion of water hyacinths on bare soils as the water level rose and provided favorable conditions for its growth and spread. The report by (Tellez *et al*., 2008) [45] strongly supports the findings, that water currents are responsible for distributing the seeds and stems of water hyacinth, allowing the weed to spread and establish itself in new areas near the water more rapidly. The speed of water currents plays a crucial role in the colonization of new areas and the spread of infestation in a specific region. The area of agriculture converted to water hyacinth was 2251.46 hectares, which was the largest change in the table. This may be due to the invasion of water hyacinths on agricultural lands as the water level rose and provided favorable conditions for its growth and spread. The decrease in the size of agricultural land, bare soils, water bodies, and other land covers observed in the study areas is consistent with the general trend in Ethiopia (Hagos *et al*., 2014) [46] and globally (Davidson, 2014) [47], where there has been a decrease in the extent of these land covers over a period of time. Different regions face different threats to wetlands, but across the board, agriculture is the primary culprit for the destruction of wetlands (Bassi *et al*., 2014) [48]. The study concluded that the increase in the area of water hyacinths was the main reason for the decline in the area of these land covers.

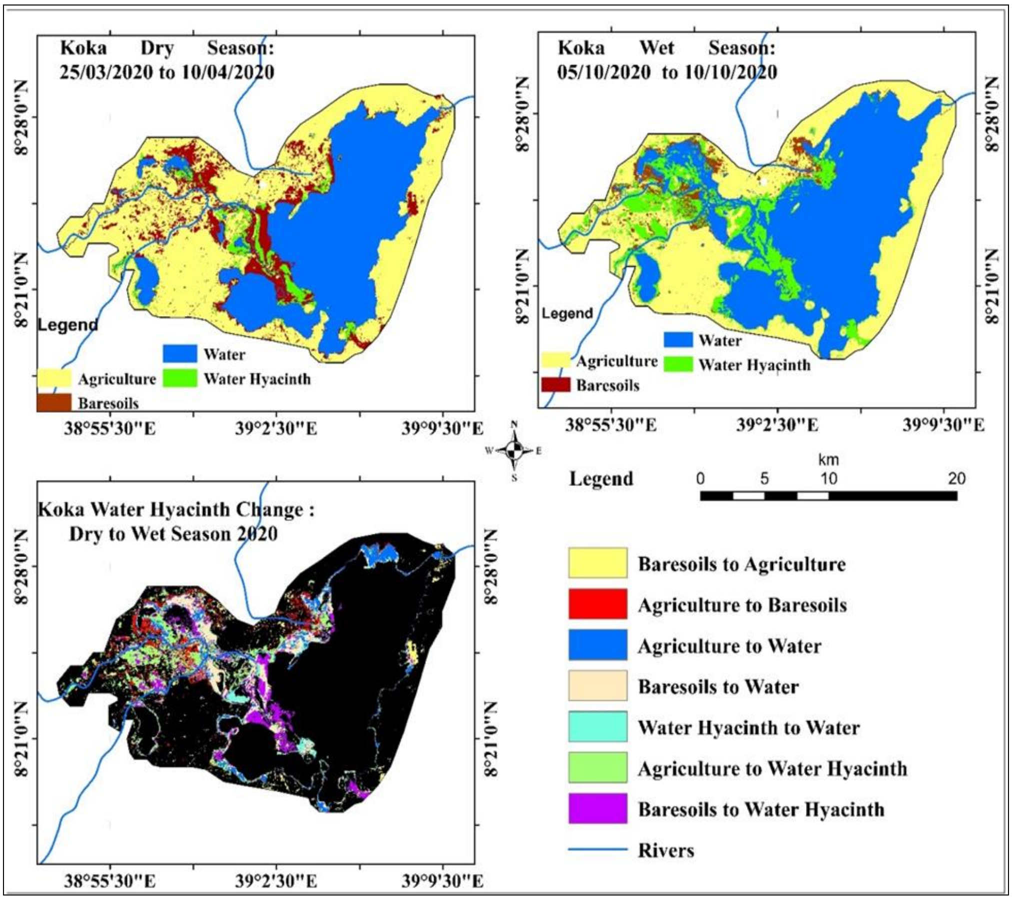

Fig 1: Lake Koka Change Analysis Map 2020

3.2 Status and distribution of water hyacinth in Lake Ziway

Ziway Lake is one of the Rift Valley lakes in Ethiopia, and it supports various economic and ecological functions, such as irrigation, fishing, tourism, and biodiversity conservation. However, the lake is facing several challenges, such as water level fluctuation, water quality degradation, and water hyacinth invasion. The LULC analysis of Ziway Lake can help to monitor and evaluate the changes and impacts of these challenges on the lake and its surroundings. Table 4 shows the LULC analysis for Ziway Lake for the dry and wet seasons of the year 2020, based on satellite imagery classification. The LULC classes are agriculture, built area, water, and water hyacinth risk. The area of the Lake Ziway covered by water hyacinth ranged from 6526.30 hectares (10.014%) of the lake area during the dry season to about 7424.05 hectares (11.39% of the lake area) during the wet season (Table 4).

Dersseh Melesse *et al*. (2020) [39] used Sentinel-2A/B satellite images to assess the spatiotemporal dynamics and environmental controlling factors of water hyacinth in Lake Ziway from 2016 to 2019. They found that water hyacinth covered 8.5% of the lake area in 2019, and that water hyacinth distribution was influenced by nutrient inputs, water level fluctuations, and wind direction.

Table 4: Ziway Lake LULC Analysis for Dry and Wet Seasons of year 2020

No.	LULC Classes	Area in Hectares	
		Dry	Wet
1	Agriculture	16137.05	14415.47
2	Built Area	771.38	771.83
3	Water	41736.92	42560.30
4	Water Hyacinth Risked	6526.30	7424.05

Table 4 reveals that water is the dominant LULC class in both seasons, covering more than 40,000 hectares of the lake area. This indicates that the lake has a large surface area and high water availability. However, the table also shows that the water area increased by about 800 hectares from the dry season to the wet season, which suggests that the lake is subject to seasonal water level fluctuation due to rainfall variation and human activities. This can affect the hydrological balance and ecological functions of the lake. The second largest LULC class in both seasons is agriculture, which occupies more than 14,000 hectares of land around the lake. This reflects the high agricultural potential and productivity of the lake basin, which benefits from the fertile soils and irrigation water from the lake. However, the table also shows that the agricultural area decreased by about 1,700 hectares from the dry season to the wet season, which implies that, some agricultural lands were flooded or abandoned due to water level rise or water quality decline. This can lead to adverse effects on both food security and the livelihoods of the communities in the area. The third largest LULC class in both seasons is water hyacinth risk, which covers more than 6,000 hectares of the lake surface. This indicates that the lake is infested by water hyacinth, an invasive aquatic weed that can cause serious environmental and socio-economic problems. According to the findings of Wassie Anteneh *et al*. (2014), the invasion of water hyacinth in Lake Tana expanded to cover an area of 34,500 hectares, constituting approximately 15 percent of the Northern shore. In this study, similar findings were observed, with water hyacinth covering 10.014% of the lake during the dry season and 11.39% during the wet season. The table also indicates that the water hyacinth risk area expanded by approximately 900 hectares when transitioning from the dry season to the wet season, implying that the weed is swiftly and forcefully spreading in the lake. This can decrease the quality of water, the diversity of species, the amount of fish, the ability to navigate, the popularity among tourists, and the overall beauty of the lake. The shape of the shores of Lake Ziway has made it easy for water hyacinths to grow and spread without being interrupted by strong winds. This is similar to a study by Willoughby *et al*. (1993) [50] which discovered that Lake Victoria in Uganda had a significant water hyacinth infestation, primarily caused by the abundance of shallow, protected bays and inlets that were mostly surrounded by papyrus plants. The smallest LULC class in both seasons is the built area, which occupies less than 800 hectares of land around the lake. This reflects the low urbanization and industrialization level of the lake basin, which may have positive effects on preserving the natural resources and ecosystem services of the lake. However, the table also shows that the built area increased slightly by about 0.5 hectares from the dry season to the wet season, which indicates that there is some development pressure and land use change in the lake basin. This can pose potential threats to the environmental sustainability and social equity of the lake.

Table 5: Ziway Lake Water Hyacinth Risked Change Analysis 2020 Dry to Wet Season Dynamics

No	Changes	Area- Hectares
1	Agriculture to Water	595.48
2	Water Hyacinth Risked to Water	361.07
3	Agriculture to Water Hyacinth Risked	1162.48
4	Water to Water Hyacinth Risked	96.79

The water hyacinth is a problematic water plant that invades and negatively affects both the environment and economy of water bodies. Ziway Lake is one of the lakes in Ethiopia that is affected by water hyacinth infestation. Table 5 shows the water hyacinth risk change analysis for Ziway Lake from the dry season to the wet season of the year 2020, based on satellite imagery classification. The table shows the area in hectares and the direction of change for four different types of land cover transitions: agriculture to water, water hyacinth risk to water, agriculture to water hyacinth risk, and water to water hyacinth risk.

Table 5 reveals that the most significant change in land cover was from agriculture to water hyacinth risk, which accounted for 1, 162.48 hectares of area. This indicates that a large portion of agricultural land around the lake was invaded by water hyacinth during the wet season, due to increased water level and nutrient availability. During the wet season, there are certain factors that facilitate the growth of water hyacinth in agricultural land around lakes. The presence of water hyacinth indicates an imbalance in the water ecosystem and it relies on the nutrients present in and around the water bodies (Gichuki *et al*., 2012) [51]. The growth of water hyacinths differs in various bodies of water around the world because of factors such as climate and season variations, fluctuations in water levels, sewage disposal, and the presence of nutrients in the water system (Thamaga and Dube, 2018) [33]. Similar causal factors can be seen in both Lake Koka and Lake Ziway. In both lakes, the presence of nutrients from agricultural areas and factories is contributing to the rapid growth of water hyacinth (EPA, 2020) [52]. Additionally, the high levels of nutrients found in urban, industrial, and municipal effluent are also causing water bodies to become infested with weeds (Jimenez, 2003) [53]. This can have negative consequences for the food security and livelihoods of the local farmers, as well as for the biodiversity and ecosystem services of the lake by reducing water quality, fisheries, navigation, tourism, and aesthetic value of the lake.

The second most significant change in land cover was from agriculture to water, which accounted for 595.48 hectares of area. This indicates that some agricultural lands around the lake were flooded or abandoned in the wet season, due to increased water level or decreased productivity. This can have negative impacts on food security and livelihoods of the local communities, as well as on soil erosion and sedimentation of the lake. The third most significant change in land cover was water hyacinth risk to water, which accounted for 361.07 hectares of area. This indicates that some areas of the lake that were infested by water hyacinth in the dry season were cleared or reduced in the wet season, due to natural or human land cover was from water to water hyacinth risk, which accounted for 96.79 hectares of area. This indicates that some areas of the lake that were free of water hyacinth in the dry season were infested by water hyacinth in the wet season, due to increased nutrient availability or decreased competition. This can have positive effects on improving water quality, fisheries, navigation, tourism, and the aesthetic value of the lake. The least significant change in this may be defined through the truth that the lakes receive sediments from upstream during flooding, which then brings nutrients that encourage the growth of water hyacinth in these areas. It has been noted that vegetation is prone to growing in shallow parts of lakes and rivers, particularly near the edge. This leads to a reduction in the size of the water body, as noted by Yigrem Mengist and Yohannes Moges in 2019 [54]. Hubble and Harper also made similar observations in 2002 [55], specifically with regards to Lake Naivasha and its seasonal shift between weed dominance on the lake surface and the shoreline. This shift is an indicator of high nutrient levels and contributes to the proliferation of water hyacinth. Previous studies (such as the one conducted by Gezie A *et al*. (2018) [56] have also shown that changes in lake water levels and intensity are important factors in the growth and spread of water hyacinths.

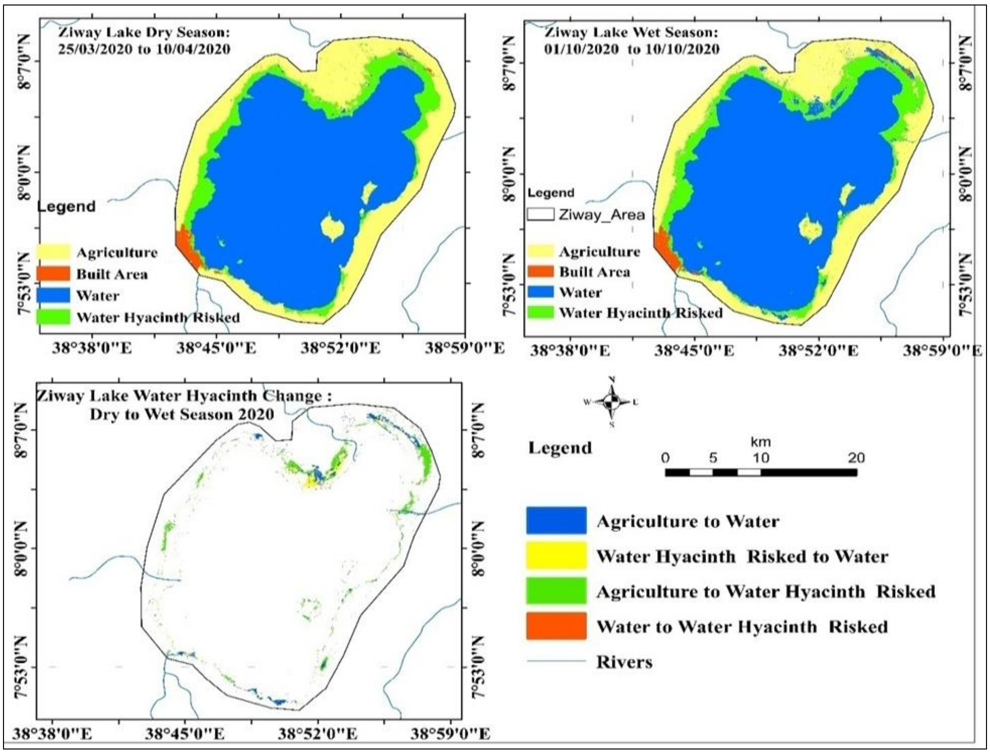

Fig 2: Ziway Lake Change Analysis Map 2020

A confusion matrix was employed to evaluate the classification accuracy. From all the classes, the land cover/use category "bare soils" exhibited low user accuracy in Lake Koka in both seasons because it occurred by the removal of weeds plus being drained by the sun. Built area and agriculture category shows low user accuracy in Lake Ziway during dry and wet seasons respectively. Results of the producer accuracy, user accuracy, overall accuracy, and kappa value confirmed the accuracy of the classifications conducted. In the wet season, producers' accuracy was between 66.7 and 100 percent; in dry season it was 50-50 percent. Lake Koka had an accuracy of 88 to 100 percent, while Lake Ziway had between 85 and 90 percent during the wet and dry seasons respectively.

The overall classification accuracy assessment was above the minimum of 85% recommended by Anderson (1971) [57]. Contrarily, the kappa values were 0.93 and 0.94, 0.935 and 0.94 for both the wet and dry seasons in Lake Koka and Lake Ziway respectively which indicate the perfect classification limit (0.81–1.00) according to Landis and Koch (1977) [58]. Therefore, the confusion matrix findings in this study indicated that the images classified were within acceptable limits.

In general infestation of water hyacinth in Ethiopia has also been manifested on a large scale in many water bodies, especially in Standing water (MWBP/RSCP, 2006) [59]. Surveys were conducted to determine the distribution of water hyacinths in Lake Koka and Lake Ziway between the dry and wet seasons of 2020. The presence of water hyacinth was discovered near the lake and its shore in shallow water. Sentinel-2 MSI satellite data, ground points, and Random Forest (RF) classification algorithm in Google Earth Engine, and TerrSet2020 were used for change analysis. Besides, mapping the spatial distribution and configuration of these species seasonally can provide better understanding of their infestation levels and assist in sustainable remediation, destroying, and management practices (Shekede *et al.*, 2008) [60]. According to the study, both lakes showed higher accuracy in classifying water hyacinth during the dry season than during those of the wet season. Additionally, the study found that utilizing an integrated dataset with spectral bands and vegetation indicators was the most efficient method for identifying and mapping the temporal range of water hyacinth in freshwater ecosystems. The findings of this study are in agreement with previous research that highlights the usefulness of Sentinel-2 MSI for mapping vegetation and aquatic environments (Dube *et al*., 2017; Shoko and Mutanga, 2017) [24, 26]. The dry season saw a more accurate distribution of water hyacinths in Lake Koka and Lake Ziway than the wet season which was true even for these species. This is likely due to variations in nutrient load and weather conditions (Tellez *et al*., 2008; Waltham and Fixler, 2017) [44, 61]. Temporal distribution in freshwater is partly due to temperature extremes caused by weather changes and flow dynamics (Thornton *et al*., 2014; Brierley and Kingsford, 2009) [62, 63]. The study's maps demonstrate how water hyacinth varies across the lake system, with seasonal changes due to rainfall and water level fluctuations. Factors such as agriculture runoff, wind direction and speed of water currents (such as in the case of Lake Koka, part of Awash Basin and Lake Ziway), changes in water-level, factory activities, and ferry navigation all play a significant role in shaping the distribution pattern and extent of aquatic plants. This was also similar to the one proposed by the reviewer that plants in deep waters have more roots compared to plants in shallow waters. Additionally, plants in shallow waters exhibit a higher leaf region and an increased growth during the summertime season (Wang *et al*., 2012) [64]. The depth of the water does not have a significant impact on the distribution of water hyacinths, but their concentration is higher at the edges of the lake where the intensity of the water is noticeably lower. During periods of rain and after it, the lake's water level rises, leading to the expansion of water hyacinth into the shallow water area of the flood plain. Water hyacinth has the ability to eliminate nutrients in both still and moving bodies of water, as stated by Rogers and Davis in 1972 [65].

4. Conclusion and Recommendations

4.1. Conclusion

The study emphasizes the considerable effects of water hyacinth, which is among the most intrusive aquatic plant species globally, on economic, social, and environmental factors. The research aimed to analyze the spatial and temporal patterns of water hyacinths in Lake Koka, a part of Awash Basin and Lake Ziway. This was done by studying satellite data during both the wet and dry seasons. The presence and spread of the water hyacinth in Lake Koka, which are part of Awash Basin and Lake Ziway, change throughout the year and are denser in these areas during the wet season.

The study's results indicated that water hyacinth was more prominent during the wet season and that both lakes were subjected to various challenges, including changes in water levels, deterioration in water quality, and the invasion of water hyacinth. Hence, the extent and distribution pattern of water hyacinth are mostly influenced by different factors depending on the season. Factors that contribute to the growth and spread of water hyacinths include powerful winds, fishing equipment, and boats, agricultural practices (such as the runoff of synthetic fertilizers during rainy periods), changes in water levels, the movement of ferries, and the colonization by other organisms. During the wet season, Lake Koka has a maximum invasion area of 4678.06 ha, which accounts for 12.44% of its total area. On the other hand, Lake Ziway has a maximum invasion area of 7424.05 ha, making up 11.39% of its total area at the highest water level.

The invasion of water hyacinth, which can grow and spread rapidly, can have negative consequences for the food security and livelihoods of the local farmers, as well as for the biodiversity and ecosystem services of the lake.

In both Lake Koka and Lake Ziway the most significant change in land cover was from agriculture to water hyacinth risk, which accounted for 1162.48 and 2251.46 hectares of area respectively. Furthermore, the study also found that human activities, such as the excessive use of synthetic fertilizers and chemicals from nearby agricultural lands and factories, have contaminated the lakes and created suitable conditions for the proliferation of water hyacinths.

Therefore, it is crucial to closely monitor, mitigate, and manage water hyacinths to prevent them from becoming a problem and eventually restore the lake's beneficial uses. It's equally important to increase community involvement in controlling and eradicating water hyacinths. This can be achieved through training, awareness campaigns, strengthening linkages, and providing resources that are not readily available to the communities.

4.2 Recommendations

The recommendations given can be made based on the outcomes

- The use of integrated and adaptive management approaches is recommended to manage the impact of water hyacinths on Lake Koka and Lake Ziway.
- The reduction of nutrient load in water bodies is necessary, and private organizations should establish a waste treatment plant before releasing it into the lake.

Early detection and monitoring are critical, also education programs should be undertaken to create awareness about the issue.

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