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# Spatio-Temporal Pattern of Water Hyacinth on Asa River, Ilorin, Kwara State, Nigeria.

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abstract

The study aims at assessing the spatio-temporal impact of water hyacinth on the Asa River, Ilorin, Kwara State. The objectives are to examine spatio- temporal distribution of water hyacinth between 2000 and 2020; determine the rate of change in water hyacinth distribution in the study area; and forecast water hyacinth coverage on the river course by year 2030. Satellite image covering the dam for specific duration was used for determining the change and rate of change in spread of water hyacinth on the dam. The satellite image was sourced from United States Geological Survey (USGS) earth explorer. Linear regression was used to forecast the spread of Hyacinth by the year 2030. The study reveals that water hyacinth distribution increases around the river from 2000 to 2020. As at 2000, the portion of the dam overgrown with water hyacinth was less than 0.028 sq km of the area covered by the river and increased to 0.664, and 2.735 sq km in the 2009 and 2020 respectively. The increase in water hyacinth coverage began at the downstream of the river where pollutants are deposited before engulfing the surroundings of the river. The forecast shows that Water hyacinth will cover about 3.9 sq.km by 2030 if no measures is put in place to mitigate the current growth rate. The study concludes that water hyacinth covers Asa River and recommends the implementation of an integrated management approach that combines mechanical, biological, and chemical control methods to effectively manage water hyacinth infestations in the Asa River.



## Introduction

Water hyacinth is a free-floating perennial aquatic plant native to tropical and sub-tropical South America, with bright green, waxy leaves and attractive, violet flowers that have yellow-striped banner petals. The leaves are arranged in a rosette. The leaf stem is usually somewhat to completely swollen and filled with spongy tissue and thus, acts as afloat (Tewabe, 2015). The water hyacinth is alien to the Nigerian water ecosystem. It was introduced as an ornamental plant, which later became a weed because of high levels of nutrients from the urban municipal, and industrial wastewater (Ovarr, 2019). After its introduction into Nigeria, several river bodies and dams, including the Asa River, have been invaded by water hyacinth. The Asa River, being a very important dam with its role in the economy and water supply of the people in Ilorin, spurred Oyedeji et al. (2013) to assess water hyacinth and duckweed as indicators of heavy metal pollution in the River Asa. Their study revealed that water pollution influences duckweed and water hyacinth blooms in the river. However, this is based on field surveys, which are limited in location and spatial extent. Therefore, there is a need for a study that examines the status of water hyacinth on a broader spatial and temporal scale. Earth observatory devices such as the Landsat satellite are useful for collecting rapid, temporal, and synoptic data regarding water bodies, which can aid in a spatiotemporal assessment of water hyacinth abundance in water ecosystems (Dalu et al., 2015).

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Higher concentrations of water hyacinth cause water resources to decline, and consequently affecting their availability for agricultural production, clogging navigation routes, disturbing aquatic life, and acting as a breeding ground for mosquitoes, snakes, crocodiles, and vectors of schistosomiasis, which can ultimately cause diseases (Villamagna and Murphy, 2010). All these problems in turn affect the socio-economics and environment of the surrounding communities (Shekede et al., 2008). Although water hyacinth invasions vary in extent and duration, they still cause similar problems. The rapid regenerative nature of water hyacinth makes it extremely difficult to eradicate once established. Therefore, the goal of most management efforts is to minimize economic costs and ecological damage. However, the management effort can best be achieved by timely information on the invasion of water hyacinth and its spread on a water body. However, a lack of up-to-date and reliable spatial information further complicates the management of this weed.

So far, management efforts rely on non-periodic surveys, which are costly, laborious, and sometimes inaccurate for integrated water resources management (Dube et al., 2017). In addition, field observations are usually only available for a few stations and often cover short periods due to the high cost of maintaining personnel and equipment to collect field data. In addition, the extent of the change can hardly be provided as measurements are only available for limited locations. Thus, historic water hyacinth information such as the occurrence, spatial extent, magnitude, and timing are scarce for most systems. This problem now has a solution with the recent simultaneous use of traditional field measurements and up-to-date earth observatory methods, also known as remote sensing (RS) (Brivio et al., 2001).

Geospatial technologies (remote sensing and geographic information systems) have since emerged as tools that offer quick and efficient methods to identify and map plant species and the associated changes over time. These technologies have so far proved useful in mapping invasive species in large water bodies such as lakes, but their performance on several dams in Nigeria remains untested due to the lack of interest from researchers (Akanbi et al., 2013). The advent of Landsat 8 Operational Land Imager (OLI) and Sentinel-2 Multi-Spectral Instrument (MSI) sensors has provided a new opportunity to derive thematic maps that can discern the spatial location and distribution of invasive water hyacinth in smaller waterbodies over time and space.

Accurate, reliable, and timely information on the spatio-temporal distribution and configuration of water hyacinth is important in tracing their evolution and propagation in affected areas, as well as the potential vulnerable areas (Thamaga and Dube, 2018). More so, the study area has been grappling with the invasive presence of water hyacinth (Eichhornia crassipes), a floating aquatic plant known for its rapid proliferation and detrimental impacts on freshwater ecosystems. The invasion of water hyacinth in the Asa River has raised significant concerns because of its adverse effects on biodiversity, water quality, and socio-economic activities in the region. This study thus, assessed the spatial and temporal pattern of water hyacinth on Asa Dam, Ilorin, Kwara State with the aid of remote sensing by examining the spatio-temporal distribution of water hyacinth between 2000 and 2020 in the study area, determining the rate of change in hyacinth distribution in the study area, and forecasting the area of the river course to be covered by water hyacinth by the year 2030.

**Effects of Water Hyacinth on Aquatic Ecosystem**

The spatial distribution and arrangement of water hyacinth negatively impact aquatic life within freshwater ecosystems (Mironga et al., 2014). Ecologically, water hyacinth can affect the productivity of zooplankton and phytoplankton, alter surface water clarity, and induce hypoxia by depleting related nutrients and contaminants like nitrogen, phosphorus, and heavy metals. Research by Mironga et al. (2014) demonstrated that areas of lakes infested with water hyacinth exhibited significantly lower ($\alpha = 0.005$) zooplankton populations compared to hyacinth-free zones in Lake Naivasha, Kenya.

This finding is reinforced by Chukwuka and Uka's (2007) study, which also noted a significant ($\alpha = 0.005$) decrease in zooplankton density in water hyacinth-infested regions of Awa reservoirs, Nigeria. The impact of water hyacinth on zooplankton populations can have cascading effects on aquatic organisms such as fish (Mironga et al., 2014). Additionally, water hyacinth tends to outcompete submerged vegetation and phytoplankton for nutrients and sunlight utilization (Wang & Yan 2017).

Furthermore, water hyacinth invasion poses a severe ecological problem in freshwater ecosystems by altering the structure, composition, productivity, and functioning of aquatic ecosystems. The blanket-like coverage of water hyacinth inhibits sunlight penetration into the water, reducing photosynthesis rates for submerged plants. The adverse effects on aquatic life diversity arise from the creation of unsuitable ecological conditions (Mironga et al., 2012; Wu et al., 2011). The reduction in oxygen levels beneath the mats lead to hypoxia and create breeding grounds for diseases, such as encephalitis and filariasis, as well as mosquito vectors of malaria and other waterborne diseases. Additionally, water hyacinth mats can disrupt natural predation, leading to imbalanced species abundances (Kateregga & Sterner, 2009). These invasive mats may also hinder certain species' breeding, nursery habitats, and feeding grounds (Twongo & Howard, 1998).

The presence of water hyacinth in freshwater ecosystems compromises water quality and quantity, especially upon decay, resulting anaerobic conditions and the release of harmful gases. Additionally, water hyacinth's highwater content increases evaporation rates (Gopal, 1987). Furthermore, its physical removal, disposal, and decomposition present health and environmental hazards, as these plants absorb heavy metals and pollutants.

**Materials and Methods**

**Study area**

The Asa River is located in Ilorin, and Ilorin is located between latitudes 8º24′ and 8º36′ north of the equator and between longitudes 4º33′ and 4º53′ east of the Greenwich meridian. It is the capital of Kwara State.


Figure 1: Asa Dam in Ilorin
Source: Adopted from (Ajadi et al., 2019).

Ilorin has a humid tropical climate that is characterized by wet and dry seasons. The wet season in the city begins towards the end of March, when the tropical maritime air mass is prevalent, and ends around October. The dry season in the city begins with the onset of the Tropical Continental Air Mass in November. This wind, which is usually predominant in the city until February, is dry and dusty and carries no moisture. It is commonly referred to as harmattan. Rainfall in the city exhibits a double maxima pattern, with peak periods in the months of June and September and a period of dry spell in July. The temperature in the town is uniformly high (between $25^0$C and $28^0$C) and open-air insolation can be very uncomfortable during the dry season (Oyegun, 1983). Evaporation values in Ilorin range between 3.1 and 7.8 mm, while potential evapotranspiration is usually the highest in January.

Ilorin is drained mainly by the River Asa. The tributaries of the River Asa in Ilorin include the rivers Agba, Aluko, Atikeke, Amule, Alalubosa, Osere, Okun, and Oyun, among others. These rivers exhibit a seasonal pattern, with minor ones drying up during the dry season (Agaja et al., 2021). The Asa River has its source in the Oyo State, South-West Nigeria, and it flows through Ilorin, the capital of Kwara State, Nigeria, in a south-north direction, forming a dividing boundary between the eastern and western parts of Ilorin metropolis. The major tributary of the Asa River is the River Awon, which continues to form one of the tributaries of the River Niger at approximately 12.2 km north of Ilorin. The River Asa is joined by the River Oyun to the east and, to the west, by the River Imoru. Afidikodi, Ekoro, and Obe are among the earliest tributaries of the Asa River, while its tributaries in Ilorin include the River Agba, Aluko, Atikeke, Mitile, Odota, Okun, and Osere (Agaja et al., 2021). The river is approximately 56 km long with a maximum width of approximately 100m within the dam site. Its total catchment area is approximately 1037 km2, lying within the Kwara State and Oyo State of Nigeria, with about one-third of the basin area located in Oyo State. Asa Dam, constructed in 1984, is a composite dam with an earth embankment at its extreme ends. The Asa River is a major water source supplying potable water to the local population through the Asa Dam. This dam was constructed to provide approximately 50,000 cubic meters of water per day to Ilorin and surrounding towns, significantly improving water availability for domestic and industrial use. Additionally, the river supports agricultural activities, providing irrigation for crops and serving as a habitat for local fisheries. The Asa River also plays a critical role in flood control, as efforts are made to clear debris to prevent flooding in Ilorin.

**Methods**

A satellite image of the dam between 2000 and 2020 was used to determine the changes that occurred both in the spread and rate of spread of water hyacinth on the dam. The satellite image was sourced from the United States Geological Survey (USGS) Earth Explorer via https://earthexplorer.usgs.gov/. Specifically, the normalized difference vegetation index derived from the satellite image was used to obtain information on the rate of spread. Therefore, the cloud-free remotely sensed Landsat 7 ETM images of 2000 and 2009, as well as the Landsat 8 OLI/TIRS images of 2020 covering the dam, were sourced from the United States Geological Survey (USGS) Earth Explorer via https://earthexplorer.usgs.gov/. The year 2009 was used instead of 2010, as there was no clear image covering the area in 2010.

In analyzing the satellite images obtained for the study, a variety of image pre-processing activities were implemented on each image before the Normalized Difference Vegetation Index (NDVI) calculation and change detection were done. These include geometric and radiometric corrections. After this, digitization of the dam was carried out before a subset was created from each large scene of the satellite imagery by using the extract and clip tools in ArcGIS 10.5 software. The NDVI was calculated as a ratio between the red (R) and near infrared (NIR) values in traditional fashion via the following equation:

$$NDVI = \frac{\mathrm{NIR} - \mathrm{Red}}{\mathrm{NIR} + \mathrm{Red}}$$

where Red is the visible red reflectance, and NIR is near infrared reflectance. In Landsat 5TM, NIR is Band 4 while red is Band 3 while in Landsat 8 OLI, NIR is Band 5 and Red is Band 4. NDVI is used to quantify vegetation greenness and is useful in understanding vegetation density and assess changes in plant health. A very low value of NDVI (0.1 and below) corresponds to barren areas of rock, sand, or snow. Moderate values represent shrub and grassland (0.2 to 0.3), while a high value indicates temperate and tropical rainforests (0.6 to 0.8). Bare soil is represented with NDVI values, which are closest to 0 and water bodies are represented with negative NDVI values (Xie et al., 2010).

The change analysis is based on the historical changes from the time (*$t_1$ to $t_2$*) (Eastman, 2012). Raster calculator in ArcGIS 10.5 was used to subtract the NDVI distribution of the different time periods to determine the extent of temporal and spatial change in water hyacinth distribution in the study area. Afterwards, the reclassify tool was used to categorize the area into hyacinth-free and hyacinth- infested water surface. The rate of change per year in water hyacinth at the dam was analyzed using the following formula:

$$\text{Rate of Change Per Year} = \frac{\mathrm{D2} - \mathrm{D1}}{\mathrm{Y2} - \mathrm{Y1}}$$

Where D1 and D2 are the areas of the target vegetation cover type at the beginning or first year (Y1) and the subsequent years (Y2) of the study period, respectively. Thus, whereas Y1 refers to the starting year, Y2 refers to the subsequent year under comparison. Linear regression was used to forecast the spread of Hyacinth by the year 2030. The linear equation used is:

$y = a + bx - e$ where $a = 0.4338$ $b = 0.139$

**Result and Discussion**

**Spatial and Temporal Distribution of Water Hyacinth in the Study Area**

The temporal distribution of water hyacinth in the Asa River reveals that there has been an increase in the area covered in 2000, 2009 and 2020, with 0.028, 0.664, and 2.735 sq km respectively are shown in Table 1. This is not far-fetched from Rahel and Oldenb's (2008) report that water hyacinth has invaded freshwater systems in over 50 countries on five continents.

Table 1: Temporal Distribution of Water Hyacinth on the Asa River between 2000and 2020

| Water Surface | 2000 | | 2009 | | 2020 | |
|---|---|---|---|---|---|---|
| | Sq. Km | % | Sq. Km | % | Sq. Km | % |
| **Dam coverage** | 8.506 | 99.66 | 7.871 | 92.2 | 5.799 | 67.9 |
| **Water Hyacinth** | 0.028 | 0.33 | 0.664 | 7.8 | 2.735 | 32.1 |
| **Total** | 8.535 | 100 | 8.535 | 100 | 8.535 | 100 |

Source: Author's Fieldwork, 2021

In 2000, only a small portion (0.028 square kilometers) of the Asa River was covered with water hyacinth (see Figure 2), while in 2009, the portion covered was about 0.664 sq km of the dam area (see Figure 3). In 2020, the portion covered increased to about 2.735 square kilometers, of the dam area as shown in Figures 4.

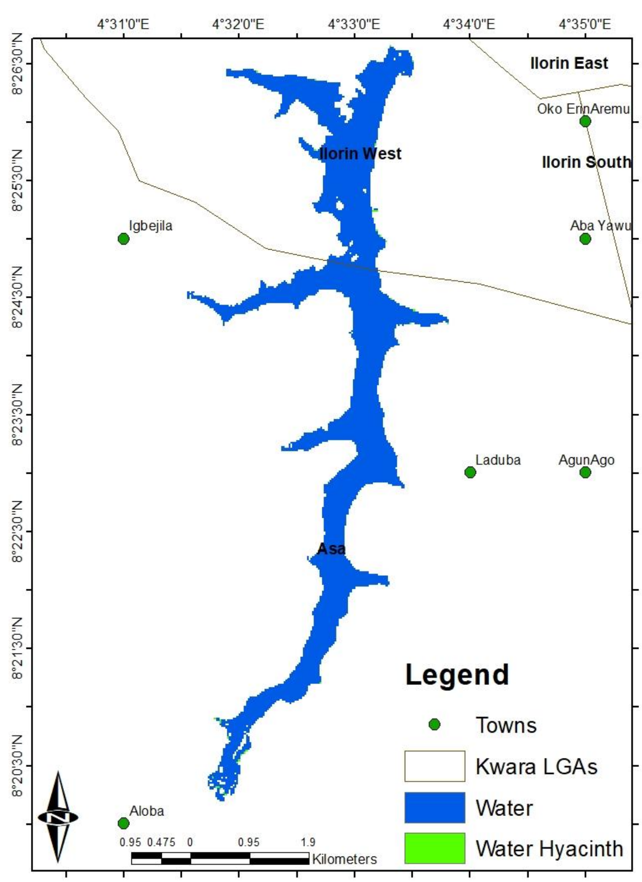


Figure 2: Spatial Distribution of Water Hyacinth in Asa River in the Year 2000
Source: Author's Fieldwork, 2021

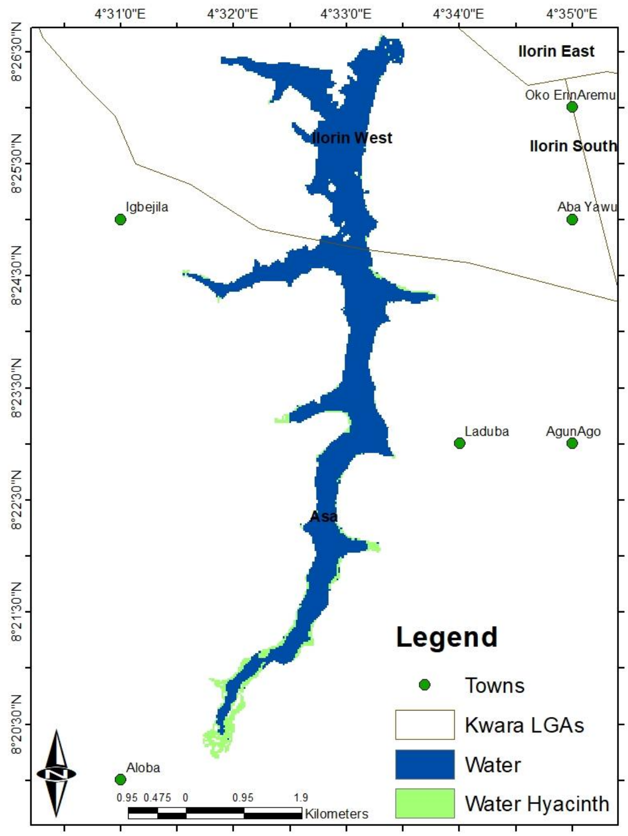


Figure 3: Spatial Distribution of Water Hyacinth in the Asa River in 2009
Source: Author's Fieldwork, 2021.

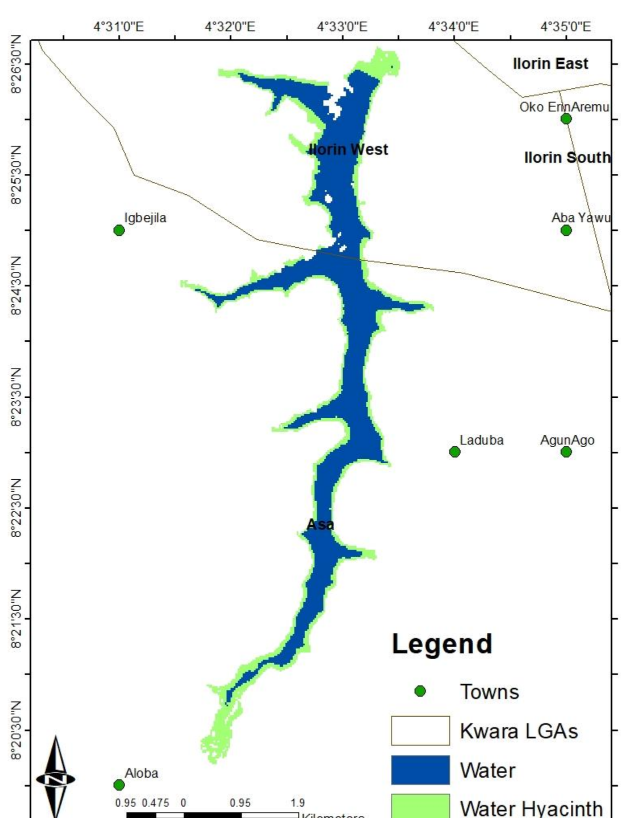


Figure 4: Spatial Distribution of Water Hyacinth in Asa River in the Year 2020
Source: Author's Fieldwork, 2021

The temporal dynamic can be observed in the spatial distribution of water hyacinth in Figures 2–4. In 2000, water hyacinth was barely visible around the dam; while in 2009, a large part of the water hyacinth was in the southern part of the dam. This could be a result of water pollution from land use being deposited in the southern part of the river. In 2020, more water hyacinth was observed around the river, which can be attributed to the increase in land use activities around the river. Among the activities observed during the fieldwork were fishing, farming, and fishing, among others. Ovarr (2019) also reported that water hyacinth became a weed because of the high levels of nutrients from urban, municipal, and industrial wastewater.

**Rate of Change in Water Hyacinth Distribution in the Study Area**

Between 2000 and 2009, the changes only affected 0.635 square kilometers, while in 2020, the changes affected 2.072 square kilometers, as shown in Table 2. This can be seen from the differences in the spatial extent of the area covered by water hyacinth in Figures 2–4. This implies that the water body's exposure to direct sunlight is decreasing. Water hyacinth can severely degrade water quality by reducing dissolved oxygen levels, increasing nutrient and heavy metal concentrations, and decreasing phytoplankton production (Jafari, 2010). This in turn negatively impacts aquatic biodiversity, with declines observed in invertebrate, fish, and waterbird communities (Harun et al., 2021). Yang (2022) also reported that water hyacinth is extremely invasive and its high reproduction rate causes water pollution, waterway closure, death of aquatic organisms and the evidence clearly shows that water hyacinth is an extremely problematic invasive species that warrants significant attention and management efforts to mitigate its environmental and socioeconomic impacts.

Table 2: Rate and Percentage of Change in water hyacinth coverage from 2000 to 2020 on Asa River

| **Surface Cover** | **2000-2009** | | **2009-2020** | |
|---|---|---|---|---|
| | Sq.Km. | % | Sq. Km. | % |
| Uninfested Water surface | -0.635 | -50 | -2.072 | 50% |
| Water Hyacinth | 0.636 | 50 | 2.071 | 50% |
| **Total** | **1.271** | **100** | **4.143** | **100** |

Source: Author's Fieldwork, 2021

The annual rate of change in area covered by water hyacinth was found to be 0.07 square kilometers from 2000 to 2009, while from 2009 to 2020, it was 0.188 square kilometers (Figure 5). Thus, if nothing is done to curtail it, the river is at risk of being covered and thereby, reducing sun penetration into the river. Hill and Coetzee (2008) also reported that water hyacinth quickly invaded and colonized slow-moving waters, resulting in thick and extensive mats that prevent access to the water surface, if proper management is not applied.

**Forecast of the Water Hyacinth Encroached Area in 2030**

The forecast of the linear trend equation $y=0.139x - 0.4338$ is positive as contained in Figure 6 and this implies that the area will experience an increase in water hyacinth encroachment by the year 2030. The forecast revealed that water hyacinth encroachment by the year 2030 would have resulted in a coverage of about 3.9 square kilometers (Figure 6). This would have resulted in the drastic obstruction of direct sunlight from the dam. The organisms benefiting from sunlight would also be affected. The rapid spread of water hyacinth was also reported by Wilson et al. (2007) as cited by Uwadiae et al. (2021). They observed that water hyacinth covers 1,000 to 2,000 hectares of Lagos Lagoon. Millions of tons of new water hyacinth grow each year, creating a menace to water safety in Lagos, especially in the Ajah area, Lagos Islands, Ikorodu, Badagry, Oworonshoki, Mile 62, and Epe. With a coefficient of determination of 98.72%, which is very high, showing that there is a very strong direct positive relationship.

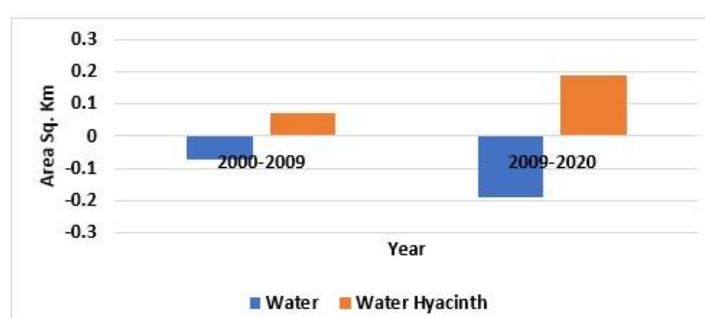


Figure 5: Annual Rate of Change in Spatial Distribution of Water Hyacinth in Asa River
Source: Author's Fieldwork, 2021

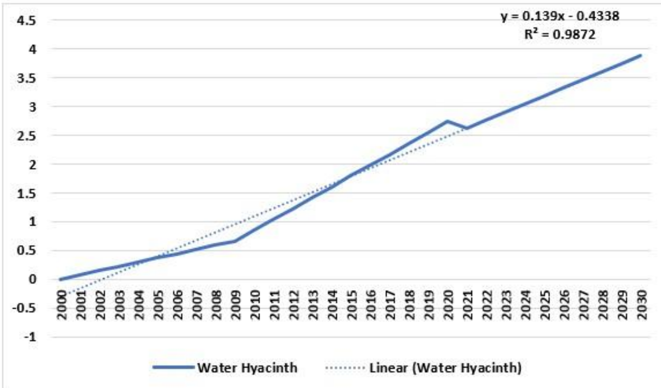

Figure 6: Forecast of Water Hyacinth Distribution on Asa River by 2030
Source: Author's Fieldwork, 2021

**Discussion**

Water hyacinth is listed as one of the most productive plants on earth and Water hyacinth shows logistic growth as similar thing happens to another floating aquatic weed. This claim on logistic growth is based on the fact that there is an increase in the temporal distribution of water hyacinth in the Asa River indicating that there has been an increase in the area covered in 2000, 2009 and 2020, with 0.028, 0.664, and 2.735 sq km respectively. (Table 2). Water hyacinth infestations change the level of oxygen in a freshwater body ecosystem, which suffocates fish and other marine organisms and alters the composition of flora and fauna. This increase will result in the altering of the clarity of water and decrease phytoplankton production, dissolved oxygen, nitrogen, phosphorous, heavy metals and concentrations of other contaminants (Villamagna and Murphy 2010). The mats of water hyacinth alter the freshwater food web, ecosystem, and shelter from pests, snakes, and insects. Also, the mats of water hyacinth plants restrict light from touching the water column, destroy biodiversity and aquatic native plants, and compete for nutrients The water hyacinth leads to excessive loss of water through evapo-transpiration, up to 1.8 times more than surface water free of water hyacinth infestation (Habtamu et al., 2019), and it leads to increased sedimentation within the delta region of Nigeria (Ndinwa et al., 2012) and constitutes breeding ground for snails, mosquitoes, and other vectors that cause diseases for humans such as malaria, dysentery, schistosomiasis, cholera, encephalitis, and filariasis (USFWS 2018). There is a very strong direct positive relationship with a coefficient of determination of 98.72% implying that by the year 2030, water hyacinth will have encroached further covering the water surface. The rapid spread of water hyacinth was also reported by Wilson et al. (2007) as cited by Uwadiae et al. (2021), who observed that water hyacinth covers 1,000 to 2,000 hectares of Lagos Lagoon yearly.

Water Hyacinth also blocks waterways and hampers navigation, affecting the boat by causing damage to the hulls as they collide with objects under Water Hyacinth marts. Several hydropower systems in the world have been affected by the infection of water hyacinth in the lakes that supply them. It hinders the generation of hydroelectric power as it limits the capacity of reservoirs to store water through the displacement of vast water volumes (Kusemiju et al.,2002).

**Conclusion and Recommendations**

In conclusion, water hyacinth cause more harm to rivers in different parts of the world. Nevertheless, the distribution kept increasing along the river Asa of the study area. The study, therefore, recommends the implementation of an integrated management approach that combines mechanical, biological, and chemical control methods such as harvesting machines, boats and barges for manual removal, barriers and Boo, introduction of natural insect predators like the weevils Neochetina eichhorniae and Neochetina bruchi., use of fungal pathogens such as Alternaria Eichhorniae, introduction of herbivorous fish species like grass carp, application of approved aquatic herbicides such as glyphosate, 2,4-D, and diquat, the use of chemicals that inhibit growth and reproduction among others to effectively manage water hyacinth infestations in the Asa River. Also, the engagement of local communities living along the Asa River in awareness campaigns and participatory efforts to control water hyacinth. Community involvement should be encouraged in regular removal efforts and the community should be educated on the negative impacts of water hyacinth on the river ecosystem and their livelihoods. While we have a vested interest in understanding the ecological dynamics of water hyacinth infestation in the Asa River, we remain committed to conducting this research with objectivity and integrity, free from any preconceived notions or biases.

**Declaration of Interest**

The study had no conflicts of interest, financial or otherwise. The study was performed solely to advance scientific understanding and inform management practices regarding water hyacinth infestations in the region. The results and interpretations presented in this research are based purely on the collected data and objective analysis, ensuring that the findings are unbiased and credible.

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