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ABSTRACT:

Globally, water hyacinth infestations are regarded as invasive weeds which tend to obstruct water channel causing considerable socio-economic concerns, decline in biodiversity and water quality. The study seeks to ascertain the quantified mass and impacts of water hyacinth infestation along three designated waterways within the Nigerian coastline; Majidun River (MR), Igbokoda water channel (IWC) and Imo River (IR) (October, 2020 – April, 2021). This project was undertaken by NIMASA, saddled with the responsibility to clear waterways for safety of navigation and prevention of marine pollution. Reconnaissance survey was carried out using ARGIS mapping to identify infested hotspots. Mechanical and manual methods were deployed for evacuation, collection, weighing and documenting the dislodged vegetation for adequate disposal. The quantified water hyacinth evacuated recorded a total of 2,298 bags with weight of 92,449 kg (w/w) across 15 hotspots at Majidum River. At Igbokoda water channel, a total of 1,625 bags with weight of 122,500 kg (w/w) across 11 hotspots, while at Imo River, Ikot Abasi a total of 1,458 bags with weight of 56,055 kg (w/w) across 6 identified hotspots. The percentage total weight of infested water hyacinth had 34.11%, 45.20%, 20.68% and with no significant differences ($p>0.05$) across MR, IWC and IR respectively. The successful removal of the infested aquatic weeds could be effectively managed through routinely monitoring of the Nigerian aquatic ecosystems protected from immense anthropogenic pressure of constant of nutrients enrichment that could further proliferate the growth of these infested weeds.

***Keywords**:* Water hyacinth infestation, Mechanical removal, Nigerian coastal environment

1.0 INTRODUCTION

Water hyacinth - *Eichornea crassipes* (Mart.) Solm-Laub. (Family Pontederiaceae) is a glabrous free-floating perennial, herbaceous, aquatic macrophyte that invades fresh water rivers and lakes and grows rapidly, forming expansive colonies of tall interwoven dense floating carpets of plants which often create impenetrable barriers and obstruct navigation. It is native to Central and South America and introduced to West Africa and Nigeria and currently found in coastal and inland waters of Nigeria (Akobundu and Agyakwa, 1987). It also infests river channels, estuaries, wetlands, streams, ponds, waterways as well as eutrophied lakes (Ndimele, 2012). Its impacts on the riparian communities range from social and economic to environmental impacts due to its potential to grow rapidly and produce enormous amounts of biomass covering extensive areas of naturally open water (Cho Mujingni, 2012). Water hyacinth belongs to the genus *Eichhornia*, which comprises seven species: *E. natans, E. heterosperma, E. crassipes, E. azurea, E. diversifolia*, *E. paniculata*, and *E. paradoxa*. Among the seven species, only two species are prolific in Africa, namely, *E. natans* and *E. crassipes*, the latter being abundant in Nigeria (Elenwo and Akankali, 2016; Opeyemi et al. 2020).

Water hyacinth Invasion Process:-Vectors and routes of introduction

The main vector of the water hyacinth today is the horticulture trade. The plant is an ornamental or lakes and rivers due to their attractive purple flower and the ability to grow well and fast. Plants can get caught on the boats engine, or stuck to its hull and can piggyback on the boat to another lake or river if the owner does not properly clean his boat. The boat can carry the seeds to another water body, and the water hyacinth will most likely be successful and grow very fast in its colonies (Arielle, 2011).

Water hyacinth is native to the Amazon in South America and especially to Brazil and Argentina. Initially intended to be given as gifts, it was introduced worldwide and has spread both accidentally and deliberately into the natural environment. Invasions have been reported in Africa especially in Nigeria, Asia, Europe, Central America, North America and the Caribbean (Zhang et al., 2010). Successful weed invasions are due to the optimum conditions provided by the invaded areas, especially in terms of temperature and nutrient levels, among other relevant factors.

Ecological and economic damages of water hyacinth

The large colonies of the water hyacinth block waterways and can affect transports and recreational boating activities due to the physical barrier (Midgley et al., 2006). Another effect is when the water hyacinth is abundant, can increase backwater and flood conditions, which would be negative for the farming community that need the runoff from their farms to be transported. This could also impede the transport and drainage of sewage that cannot be moved because of the thick roots that the water hyacinths have. These are all not only ecological damages but economic damage as ~~not~~ the cost to remove hyacinth is high, ~~but~~ the damage to boats and farms, as well as the drainage of sewage can be costly to fix and can have potential health risks to the surrounding people. Raw sewage that cannot be moved or cleared will propagate and promote the growth of different algae, like blue-green that can decrease the dissolved oxygen in the water body. If that body of water is a source that feeds the surrounding people, it can cause illnesses due to the blue-green algae being consumed (Arielle, 2011).

Other ecological effects are the out competing of water hyacinth on other native species of plants. Water hyacinth, like many plants, is more effective with the presence of nitrogen and phosphate, and as a result, is more successful at germination. Shading out of the aquatic plants below the water hyacinth, due to the colonies of mats it produces (Villamagna and Murphy, 2010).

Impact of water hyacinth on aquatic ecosystem

The structure of a macrophyte community plays a large role in determining community composition of phytoplankton, zooplankton and fish in freshwater ecosystems (Meerhoff et al., 2007). The plant provides complex structure to the upper portion of the water column that may be novel in ecosystems that otherwise lack floating vegetation (Arora and Mehra, 2003). The interconnectivity among organisms within an aquatic system makes the plant's overall influence challenging to assess. A shift in the primary-production base of a lake can resonate throughout the ecosystem, affecting multiple trophic levels both directly through changes in habitat availability, and indirectly through shifts in energy pathways.

Problems Associated with Water hyacinth

Water Hyacinth is considered to be a nuisance for the following reasons (Never, 2016): (a). Physical Problems- Water hyacinth mats clog waterways, making boating, fishing and almost all other water activities impossible; (b) Ecological Impacts- Water hyacinth mats degrade water quality by blocking photosynthesis, which greatly reduces oxygen levels in the water. It creates a cascading effect by reducing underwater life such as fish and other plants; (c). Biological Diversity- It reduces biological diversity, alters immersed plant communities by blocking access to the water and eliminating plants the animals depend on for shelter and nesting; (d). Recreational Effect- Water hyacinth will block human access to the water for swimmers, divers, boaters, fishermen, etc. The mats will reduce underwater visibility; (e). Health Risk- The water hyacinth mats are likely to provide cover for lurking snakes and crocodiles; (f). Economic Impacts- In Nigeria millions of Naira is spent annually to remove water hyacinth from the waterways, It can block completely access to water transportation in the riverine areas and lagoon. The water hyacinth mats are likely to stuck / foul boat propellers, which can lead to boat mishap and loss of life and properties; (g). Flooding- Floating mats dominated by large grasses my drift away or be grounded. This process can lead to shallow areas of water being converted to swamps; the reduced water flow can cause flooding and adversely affect irrigation schemes (Toft et al., 2003); (h). Water quality - It has a direct effect on water quality. It absorbs large amounts of nitrogen and phosphorus, other nutrients and elements; (i). Human Diseases - The conditions created by water hyacinth encourage the vectors of several human diseases, including the intermediate snail hosts of bilharzia and most mosquito vector, besides those responsible for transmission of malaria and filariasis; (j). Obstruction to Water Transport- Access to harbour and docking areas can be seriously hindered by mats of water hyacinth. Canals and freshwater rivers may be impassable as they clog up with densely intertwined carpets of the weed; (k). Clogging of intakes of irrigation, hydropower and water supply (Masifwa et al., 2001)

Management strategies and control methods

Biological controls: Insects; the introduction of non-native insects however can be risky as you may also damage the native populations of the region and may end up as

becoming a nuisance species itself. Mechanical controls – this is managed manually and heavy duty machineries such as swamp devil and weed harvester, however, this is one of the most useful method for the removal of the infested water hyacinth. chemical controls: There are also several chemical controls for the water hyacinth. Such examples are penoxsulam, glyphosate, imazamox etc. The risk associated to using this method is the killing of native plants along with the noxious weed. One other risk would be the increase of dead or decaying organic material in the body of water, changing the water chemistry and health status of aquatic biota (Never, 2016).

United Nations Conference on Environment and Development, 1992

The Federal Government of Nigeria keyed into the United Nations commission on sustainable development, Agenda 21 whose measures or policy were adopted to ensure protection and control of marine pollution.

I. To improve the income of the local communities living in the riverine areas.
II. Reduce the health risk associated with the presence of water hyacinth.
III. Improve access to the coastal ecosystems and reduce the risk associated with maritime transportation.
IV. Improvement of the lake, lagoon and river shore environment.
V. It will improve the quality of the water. The underwater will be clean and clear for visibility.
VI. Clean environment will be attractive to swimmers and divers.
VII. Safety – the waterways will be safe for foreign vessels, boats and other water crafts movement

Project operations on water hyacinth removal

The project operations on water hyacinth removal across the three locations (Majidun River, Igbokoda water channel and Imo River) was saddled by the Nigerian Maritime Administration and Safety Agency (NIMASA) with the responsibility to clear waterways free of aquatic weeds which constitutes the actual implementation of an approved work plan, conducting a reconnaissance survey and removal/evacuation of the infested aquatic weeds. The project operations include the following sub-phases: Mobilization of equipments (machineries and tools); Clearing and Removal Phase; Mapping and documentation phase; Estimation of clearing water hyacinth biomass phase; Waste Disposal/ Management Phase: and Record Keeping/ publication as illustrated in Figure 1. Hence, this study was aimed towards the evaluation of Water

hyacinth (*Eicchornia crassipes*) infestation in Nigerian Coastal Environment: Sources, Prevalence and management.

Figure 1: Operational process on the evacuation of water hyacinth

2.0 Material and methods

Field procedures of the Reconnaissance Survey

A reconnaissance survey was carried out across three (3) regions – Majidun River in Lagos State, Igbokoda River in Ondo State and Imo River in Ikot Abasi, Akwa-Ibom State to identify strategic hotspots and distributed containment of water hyacinths/ obstructive aquatic weeds using aerial coverage drones and GIS approach to appropriately identify the geomgraphical locations and proximity of these invasive weeds to coastal communities (Figure 1 and Table 1). The prevention of invasive aquatic weeds in coastal environment are of key importance, hence the need to identify the distribution pattern, and containment hotspots as well as the removal of water hyacinth. During the reconnaissance survey, prior before the pre-mobilization assessment of the project site, sensitization and awareness campaign were conducted across the three regions to sensitize the neighbouring communities of the coastal regions on the impacts of these aquatic weed infestation due to their anthopogenic activities and discharges into the water column.

Description of Project Area

The Nigerian coastline covers a total length of approximately 859 km and it is divided into four geomorphic plain zones (from east to west) namely the strand coast/estuary,

Niger-Delta, Transgressive mahin mud coast and the Barrier beach on the lagoon coast complex (Udo, 1970, Olowokudejo and Oyebanji, 2016). It stretches Inland for a distance of about 15 km in Lagos to about 100 km in them Niger Delta and about 25 km east of the Niger Delta.

Majidun River

Majidun River is one of the important rivers in Lagos State within the Western part of Nigeria. It is noted for artisanal fisheries and transportation. River Majidun is located in Ikorodu Local Government, Lagos State, Nigeria. The river was selected on the basis of the wide spread mat of water hyacinth in the water way (Sunday, 2002). The GPS coordinates (Figiure 2a) of the water hyacinths, free floating in a large stationary mass location hotspots were noted for the purpose of effective documentation and production of distribution maps. Under high tide units of mats break away from the large one and become floating or held back by mangrove roots. The aquatic weeds consisted of a few floating masses of sizes ranging from few centimeters to 10 meters and large collections/growths of water hyacinths on muddy flats. Such muddy flats could be as a result of dead decayed water hyacinths and perennial/ other weeds in the area, constituting organic matter decayed over time.

Igbokoda Water Channel (Ondo State)

The Igbokoda water channel (Figure 2b) is a creek comprised of different types of mangroves - white and red and other vegetations. It is a home for fishery, and agricultural activities where the locals chiefly rely on fishing as their source of income and livelihood. The Igbokoda channel is made-up of four (4) axes with an opening to the Atlantic Ocean. The discharges from domestic and agricultural activities from the commuities enriches the water column with nutrients and proliferate the growth of water hyacinth weed and other aquatic weeds. Fishers boats sometimes generate spent oil on the surface of the water and accumulated in the stolon and rhizomes of water hyacinths. A wide range of water hyacinth along Igbokoda Channel in Ilaje Local Government Area, Ondo state, Nigeria. It only occupies a large percentage aligned with the mangroves and floats on the surface of the water column. The presence of the water hyacinth spread could threaten aquatic biodiversity and assets within the Igbokoda channel.

Imo River

The Imo River lies within Ikot Abasi area of south-eastern and borders River State in Nigeria (Figure 2c), delimited by longitudes 7°32' and 7°35'E and latitudes 4°32' and 4°36'N covering an area of about 4.8 km^2. Drainage in the area is by the Imo River and associated creeks (Shooter and Esene) with a number of tributaries giving a dendritic drainage pattern. The area belongs to the flat-lying part of the Cenozoic Niger Delta basin with dominance of alluvial and beach sands. The main occupations of the inhabitants of the coastal vegetation include fishing, subsistence farming, water transportation business, trading, and a few are government workers. The river is made up of Mosaic forest comprising of the mangrove and secondary regrowth vegetation. Common species are *Rhizophora racemosa*, *Nypa fruticans*, *Lonchocarpus sericeus*, *Artocarpus altilis*, *Drepanocarpus lunatus* (Olowokudejo and Oyebanji, 2016).

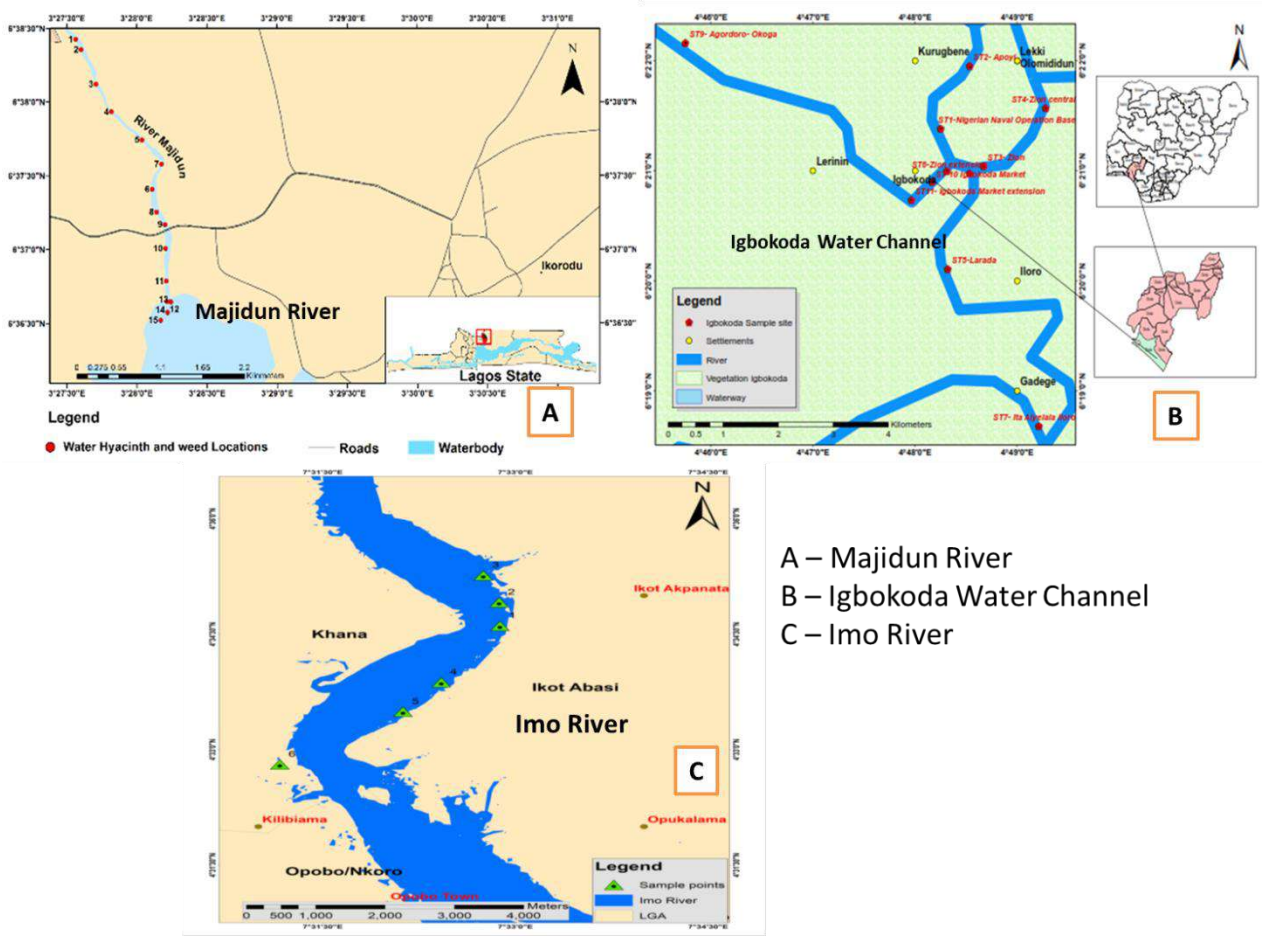


Figure 2: Map of sampling locations (Igbokoda, Majidun and Imo Rivers)

Table 1: GPS coordinates of identified hotspots of water hyacinths

Hotspots	Majidun River		Igbokoda Water channel		Imo River	
	Lat (N)	Long (E)	Lat (N)	Long (E)	Lat (N)	Long (E)
1	6.6315	3.4631	6.3566	4.8055	7.5478	4.5767
2	6.6349	3.4612	6.3657	4.8097	7.5478	4.5818
3	6.6391	3.4597	6.3531	4.8097	7.5458	4.5877
4	6.6398	3.4587	6.3595	4.8213	7.5404	4.5979
5	6.6285	3.4668	6.3354	4.8071	7.5354	4.5582
6	6.6263	3.4693	6.3496	4.8089	7.5225	4.5468
7	6.6249	3.4602	6.3114	4.8209		
8	6.6205	3.4684	6.3501	4.8052		
9	6.6192	3.4691	6.3694	4.7625		
10	6.6168	3.4699	6.3504	4.8033		
11	6.6130	3.4696	6.3513	4.8019		
12	6.6107	3.4702			**Hotspots**:	
13	6.6107	3.4707			Majidun River = 15, Imo	
14	6.6095	3.4703			River = 6 Igbokoda water	
15	6.6086	3.4695			channel = 11	

Method of Removal

The control measures that had been implemented for the purpose of this study was dependent on the depth of the water and area of the location. Manual method was utilized for two locations – Majidun and Imo Rivers on the basis of the depth which has an average of 2.5 m and inaccessibility of machinery via waterways, compared to Igbokoda water channel which has an average of 5 m and easy accessibility either via the open sea connecting from Lagos or land-based via Okitipupa, Ondo State.

Manual Method of Removal

The manual control approach utilized for the removal of water hyacinth and other aquatic weeds involves clearance by cutting from the rhizomes in mat form, while detached floating weeds are handpicked and loaded into wooden motorized and non-motorized boats. The harvested aquatic weeds are evacuated to the jetty, bagged and weighed on scale before loaded into truck and transported for management (some are buried for composting and feed formulation for farmed animals). The manual operations on the removal of water hyacinth are presented in plate 2.

Mechanical Method of Removal

The mechanical method involves the utilization of weed harvesters for harvesting detached and floating aquatic weeds and excavator tractor for evacuation. Scoop nets with small mesh size were used for pickup leftover due to the seedlings to prevent regrowth if the water column is enriched. The mechanical operations on the removal of water hyacinth are presented in plate 2.

Water Hyacinth Qualification

Immediately after evacuation of the water hyacinth, the invasive aquatic weeds were bagged counted and weighed at individual hotspots across the three locations. The cleared water channel is showed in Plate 3.

Identification, mapping and removal of water hyacinth

Aerial surveillance of the mat of the water hyacinth captured using Drone to capture the hotspots of the infested water hyacinth within the waterways.

Plate 1: Water hyacinth masses by the mangrove swamp releasing small mats into the river

Plate 2: Manual and mechanical removal of water hyacinth and other obstructive aquatic weeds

Plate 3: Cleared water channel of water hyacinth and other obstructive aquatic weeds

3.0 RESULTS AND DISCUSSION

Spatial distribution of Water hyacinths

The spatial distribution of the weight and quantities of water hyacinth infested at Majidun River (Figure 3) showed significantly high weighted and quantity at hotspot

13 and lowest at hotspot 9. Statistically, there were no significant differences ($p>0.05$) between the sampling hotspots in Majidun River. Furthermore, the spatial distribution of the weight and quantities of water hyacinth infested at Imo River (Figure 4) showed significantly high weighted and quantity at hotspot 6 and lowest at hotspot 1 and 2. Statistically, there were no significant differences ($p>0.05$) between the sampling hotspots in Imo River.

While, the spatial distribution of the weight and quantities of water hyacinth infested at Igbokoda water channel River (Figure 5) showed significantly high weighted and quantity at hotspot 10 and lowest at hotspot 5 and 7. Statistically, there were no significant differences ($p>0.05$) between the sampling hotspots in Igbokoda water channel.

The total weight and quantities of water hyacinth and other obstructive aquatic weeds are presented in Table 2. The total weights across the locations were 92,448 kg, 55,055 kg and 102,891 kg for Majidun River, Imo River and Igbokoda water channel respectively. The relative importance of sexual reproduction in the spread of *E. crassipes* in different areas is very difficult to assess and has rarely been quantified in areas of invasion (Pieterse and Murphy, 1993). The complexity of seed bank dynamics makes it difficult to predict germination responses (Vécrin et al., 2007). If water hyacinth seeds drop into water enriched with phosphates, they will germinate with very fast velocities (Albano Pérez et al., 2011).

The Dendogram showed the similarity in terms of total weight and quantities of water hyacinth infestation across the three locations (Figure 6a). The cluster analysis Dendogram plot indicates that Majidun River and Igbokoda Water Channel (South-West/South, Nigeria) receive the water hyacinth from similar source and influenced by similar environmental factors on the basis of proximity compared to Imo River which showed dissimilarities from source point receiver of the infested aquatic weeds (South-South, Nigeria).

The percentages of the weight of water hyacinth infestation across the three regions are presented in Figure 6b. The percentage total weight of infested water hyacinth had, 45.4 %, 34.2 % and 20.4 %with no significant differences (*$p>0.05$*) across MR, IWC and IR respectively. The total biomass of water hyacinth harvested in the study areas indicate significant infestation established within these aquatic communities. Ogamba et al., (2015) reported that water hyacinth are comprised of the some elemental constituent such as : C, O, Na, Mg, Al, Zn, K, Ca, Fe, P, and S, with carbon and oxygen having the highest percentages, making it

a good source of biofuel for feedstock. This could be exploited by the riparian communities for economic benefits (Adewumi and Ogbiye, 2009).

Water Hyacinth for Biofertilisers

The harvested water hyacinths are left to dry on land distance away from the coastal environment which quickly wilt and naturally composted. Cleared land with a pile of water hyacinth leftovers will quickly enter secondary succession driven by the nutrients provided by the composted weed through natural fertilisation. Rich in organic nutrients, water hyacinth consists of more than 70% organic matter on a dry basis and high levels of nitrogen (N), phosphorus (P) and potassium (K) content (Ilo et al., 2020). Water hyacinth can be either mulched (Indulekha and Thomas, 2018), composted and vermicomposted (Nath and Singh, 2016) or anaerobically digested (Sharma and Suthar, 2021) for biofertilisation purposes.

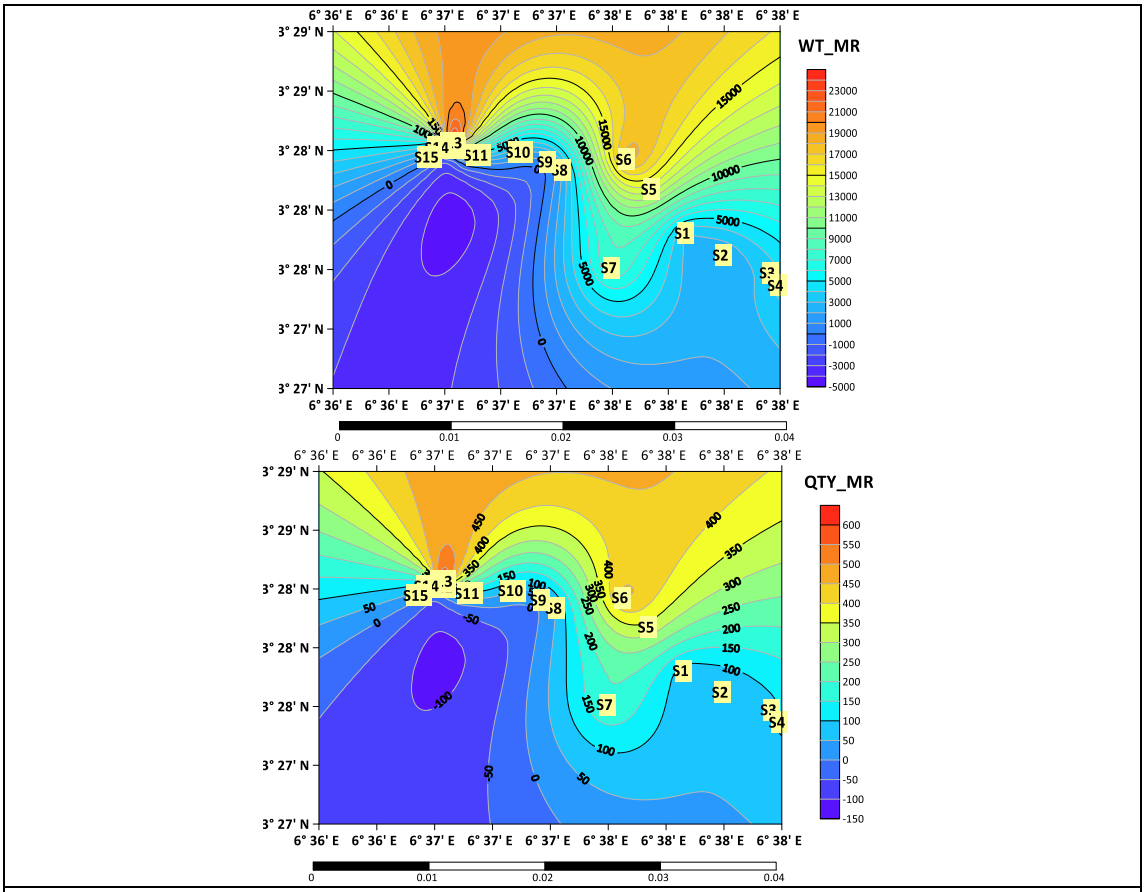


Figure 3: Contour map of the spatial distribution of total weight and quantities of water hyacinth (w/w) across Majidun River Channel

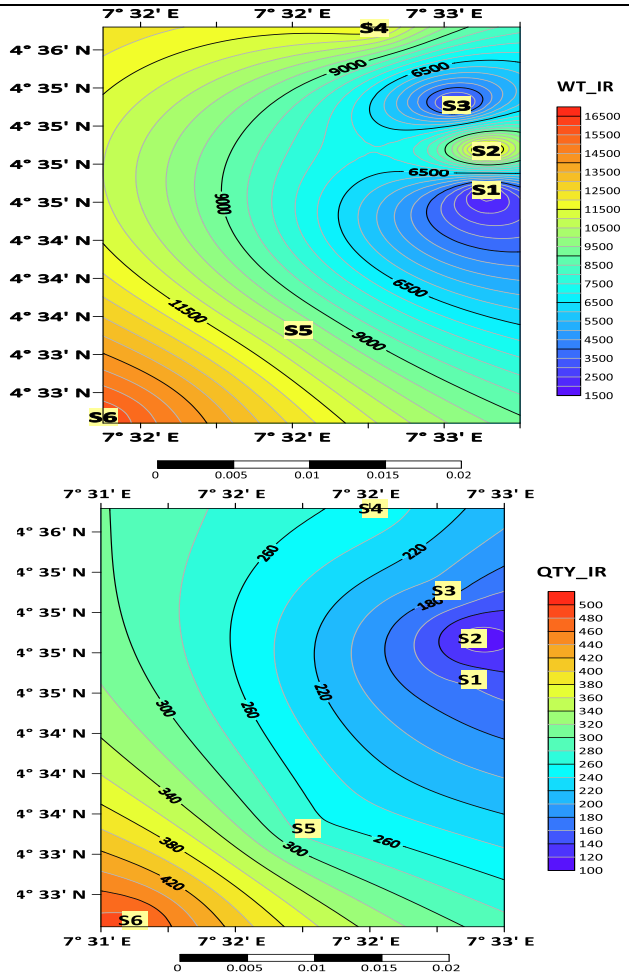
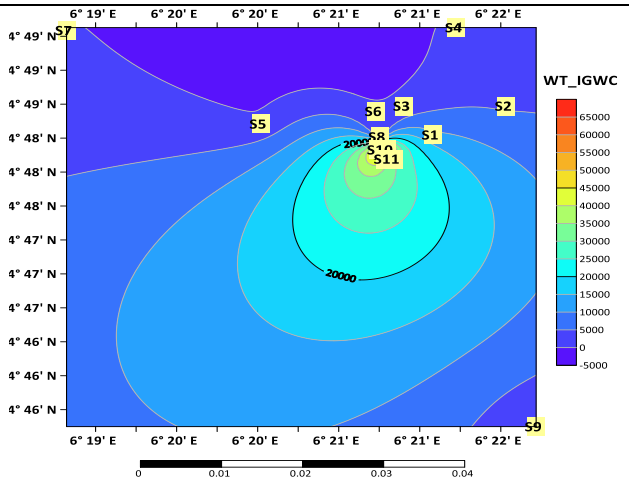


Figure 4: Contour map of the spatial distribution of total weight and quantities of water hyacinth (w/w) across Imo River Channel



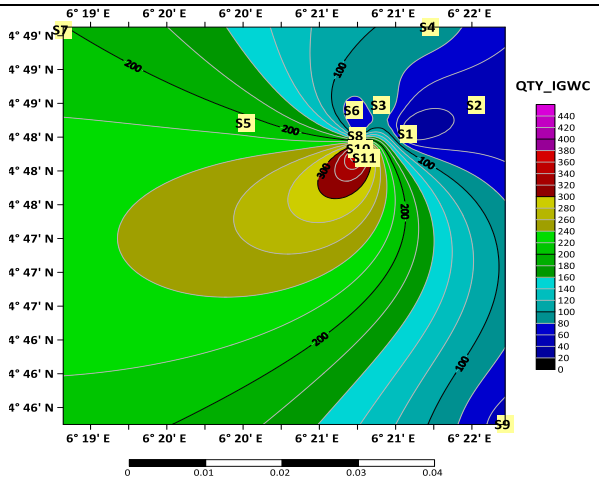


Figure 5: Contour map of the spatial distribution of total weight and quantities of water hyacinth (w/w) across Igbokoda water channel

Table 2: Quantities and weiight of evacuated water hyacinth and other obstructive weeds across Majidun River, Imo River and Igbokoda water channel (wt kg)

Majidun River			**Igbokoda channel**			**Imo River**		
Hotspots	QTY	WT	**Hotspots**	QTY	WT	**Hotspots**	QTY	WT
1	72	2897	1	16	11098	1	156	1,507
2	51	2052	2	47	4511	2	104	13,380
3	88	3540	3	109	2073	3	189	2,049
4	109	4385	4	96	1028	4	254	12,057
5	336	13517	5	208	899	5	268	10,025
6	465	18707	6	61	1010	6	487	16,037
7	201	8086	7	201	431	**Total**	1458	55,055
8	54	2172	8	67	1162			
9	13	523	9	47	1098			
10	45	1810	10	452	67,110			
11	81	3259	11	321	32,080			
12	97	3902	**Total**	1625	122,500			
13	639	25707						
14	21	845						
15	26	1046						
Total	2,298	92,449						

QTY – Quantities (Numerical counts per weighed bag); WT – Weight (kg)

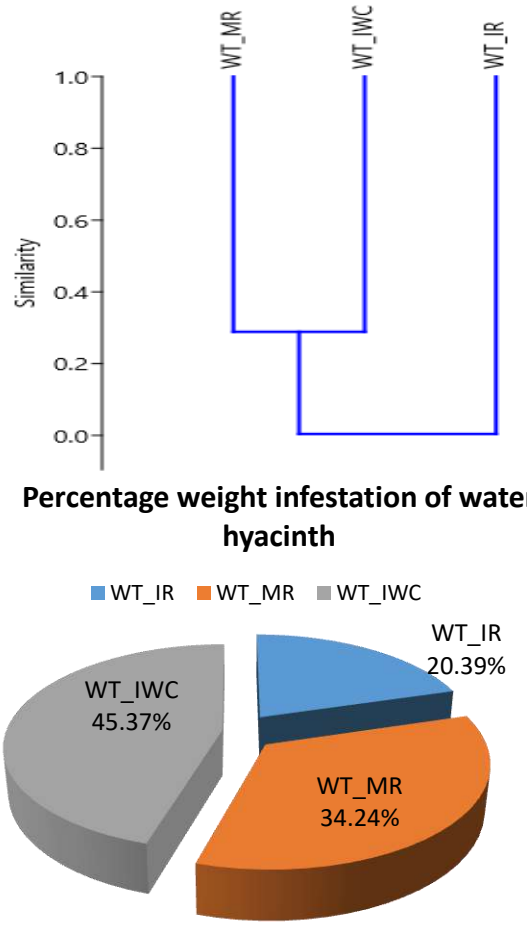


Figure 6: (a) Bray-Curtis similarity index of total weight of infested water hyacinth across three zones; (b) Percentage total weight of infested water hyacinth

4.0 CONCLUSION

The community's stakeholders were duly sensitized on the impact generated from their activities in order to prevent the enrichment of the water. The infested water hyacinth and other obstructive aquatic weeds were adequately harvested and evacuated from the three locations (Majidun River, Igbokoda Water Channel and Imo River), taking into consideration routine monitoring and quick response manually by the locals. The water channel are cleared and free to avoid incidents ranging from clogging propellers of boats, disruption of fisher folks casting nets and increase travel time.

5.0 RECOMMENDATION

The impacts of these invasive aquatic weeds are diverse as they proliferate faster under favourable environmental conditions and their significance in ecosystems,

especially in water bodies such as Rivers, Estuaries and Creeks cannot be overlooked. Water hyacinth needs to be managed strategically to tolerate sustainable exploitation and exploration of mitigation measures, to minimize potential negative impacts often associated with their massive proliferation.

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