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Nymphaea lotus Distribution in Oguta Lake: Implications for Heavy Metal Pollution in Surface Water and Sediments

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Abstract:- Water quality is increasingly deteriorating and has affected lakes, which are important sources of freshwater. Heavy metals are of great concern because they are mostly toxic and resistant to decomposition. Aquatic macrophytes serve as stable biological filters that purify water bodies by accumulating dissolved metals and toxins in their tissues. Given their ability to trap various toxic heavy metals, the macrophyte *Nymphaea lotus*, which is observed on the surface waters of Oguta Lake, was studied to estimate the concentrations of six heavy metals in the water, sediment, and macrophytes. This was achieved by studying the spatial and temporal distribution of Nymphaea lotus in the lake and analysing the concentrations of heavy metals in the surface water, macrophytes, and sediment samples. Descriptive statistics, exploratory data analysis, and correlation analysis were used to analyse data obtained. Results revealed that the population of *Nymphaea lotus* declines over time from June to November in all regions. Upstream had the highest concentration of macrophytes (64%), while the downstream area has the lowest (2%). The heavy metal concentrations in the three samples ranges from 0.16 mg/kg to 2.96 mg/kg in sediments and *Nymphaea lotus*, and from 0.16 mg/L to 2.16 mg/L in water, with lead showing the highest concentration across all sample type. This highlights heavy metal contamination in the lake. The sparsely populated Nymphaea lotus exhibits selective bioaccumulation of lead, mercury, and zinc, while it seems to exclude or inefficiently absorb arsenic and chromium. Correlation analysis suggests a close interdependence between the concentrations of metals in sediments, water, and macrophytes, with sediments playing a key role in both water contamination and macrophyte metal absorption. Corrective and preventive measures should be taken to restore the lake.

I. INTRODUCTION

Water quality is increasingly deteriorating, which is a cause of global concern. Water is contaminated when natural processes or anthropogenic activities, alter the acceptable quality to a greater extent that its intended use for commercial and domestic purposes is hampered. In developing countries, lakes are primarily used by locals for transportation, fishing, washing, cooking, and irrigation practices (Okoro et al., 2014). However, recent records indicate that anthropogenic activities have altered the acceptable quality of these water bodies to the extent that its use for commercial and domestic purposes is increasingly becoming unsafe.

Lakes and rivers are important sources of fresh water, but they are polluted by natural and anthropogenic sources (Umunnakwe & Aharanwa 2014). Soil geochemical composition is a natural source through which heavy metals get into water bodies, whereas industrial effluents, run-offs from contaminated sites and agricultural farmlands and other various developmental activities are anthropogenic sources. (Kapoor et al. 2021). The types of contaminants introduced into aquatic ecosystems are influenced by the kind of anthropogenic activities embarked upon within the surrounding.

Heavy metals are of great concern because they are mostly toxic and resistant to decomposition. When heavy metals are discharged into aquatic environments, they gradually get dispersed through physical accumulation of metal-enriched particulate matter by sedimentation, chemically by adsorption from water column and biological uptake by organisms. (Reymond and Sudalaimuthu, 2023; Sahoo et al., 2023; Sonone et al., 2020; C. Zhang et al., 2023; L. Zhang et al., 2022

Pollution sets in when the self-purification mechanism of water is defeated, and these heavy metals go beyond the permissible limits in the water. The enrichment of heavy metals in aquatic organisms can be transformed into more toxic organic complexes, which can cause environmental problems, human health risk and biological hazard risk through the food chain (Sahoo et al., 2023; Peralta-Videa et al., 2009; Zaynab et al., 2022).

Some studies have assessed the water quality of Oguta Lake and have found that the heavy metals and physicochemical parameters investigated were within WHO maximum permissible limits. (Umunnakwe & Aharanwa, 2014; Egereonu et al. 2015; Ogunfowokan et al. 2013; Emele et al. 2021; Atawal Andong ET AL. 2019; Madu et al. 2022)

Many aquatic macrophytes are recognized as effective scavengers of heavy metals in water and wetland environments (Gulati et al., 1979). These plants absorb metals from their surroundings (Ali and Soltan, 1999; Oyedeji et al., 2013) and influence metal dynamics within these ecosystems (Jackson et al., 1994; Kara, 2005). Aquatic macrophytes can uptake metals from water, resulting in internal concentrations that are significantly higher than those in their environment. This process of bioaccumulation in aquatic macrophytes has proven valuable for monitoring and improving the quality of water bodies (Wang and Williams, 1988; Dunhabin and Bowner, 1992; Whitton and Kelley, 1995; Vajpayee et al., 1995).

Nymphaea lotus (Water lily) is an herbaceous aquatic macrophyte, it is widely distributed in streams, lakes, rivers, and ponds (Fayed and Abdel-shafy (1985). Leaves of *Nymphaea lotus* (Water lily) also called lily pads are thick and buoyant leaves that float along the water surface, with the stem of all *Nymphaea lotus* reaching deep below water surface and onto the muck and mud of the lake or pond bottom. The stems maintain their hold even under strong currents while photosynthesis and gas exchange occur in the lily pads. Some parts of *Nymphaea lotus* are cooked and eaten as greens, while others are dried and ground into a powder for use as a thickening agent or flour (Skinner, 2006). Although *Nymphaea* is sometimes considered a nuisance, its use traditionally in medicine for the treatment of different ailments have been documented. (Steven & James (1990); El Ghazali et al. (1994); Shin-chen (1973); Skinner (2005). If left unchecked, *Nymphaea lotus* can grow out of control and disrupt fragile ecosystems.

II. MATERIALS AND METHODS

➢ *Study Site*

Oguta Lake is in Imo State, in southeastern Nigeria. The lake sits on a low-lying platform, at an elevation of 50 meters above sea level, positioned between latitudes 5°4'' and 5°44' N, and longitudes 6°45' and 6°50' E. Four rivers—Njaba, Awbana, Utu, and Orashi—are connected to Oguta Lake (Ahiarakwem and Onyekuru, 2011; Atawal Andong et al. 2019), playing a vital role in its water recharge. The Njaba and Awbana Rivers continuously discharge into the lake, while the perennial Utu Stream contributes during the rainy season. The Orashi River flows to the southwest of the lake. The total annual inflow from these rivers and streams is estimated at 25,801.60 m^3 (Ahiarakwem, 2006). Additionally, the annual return flow and overland runoff into the lake are estimated to be 69,000 m^3 and 138,000 m^3, respectively, with an annual recharge from precipitation around 693,000 m^3. The groundwater inflow into the lake is also estimated to be approximately 2,750,400 m^3 (Okoro et al., 2014; Ahiarakwem et al., 2012). The lake's surface area ranges from 1.8 km^2 to 2.5 km^2, and it has a shoreline length of about 10 km, with maximum and mean depths of 8.0 m and 5.5 m, respectively (Nfor and Akaegbobi, 2012).

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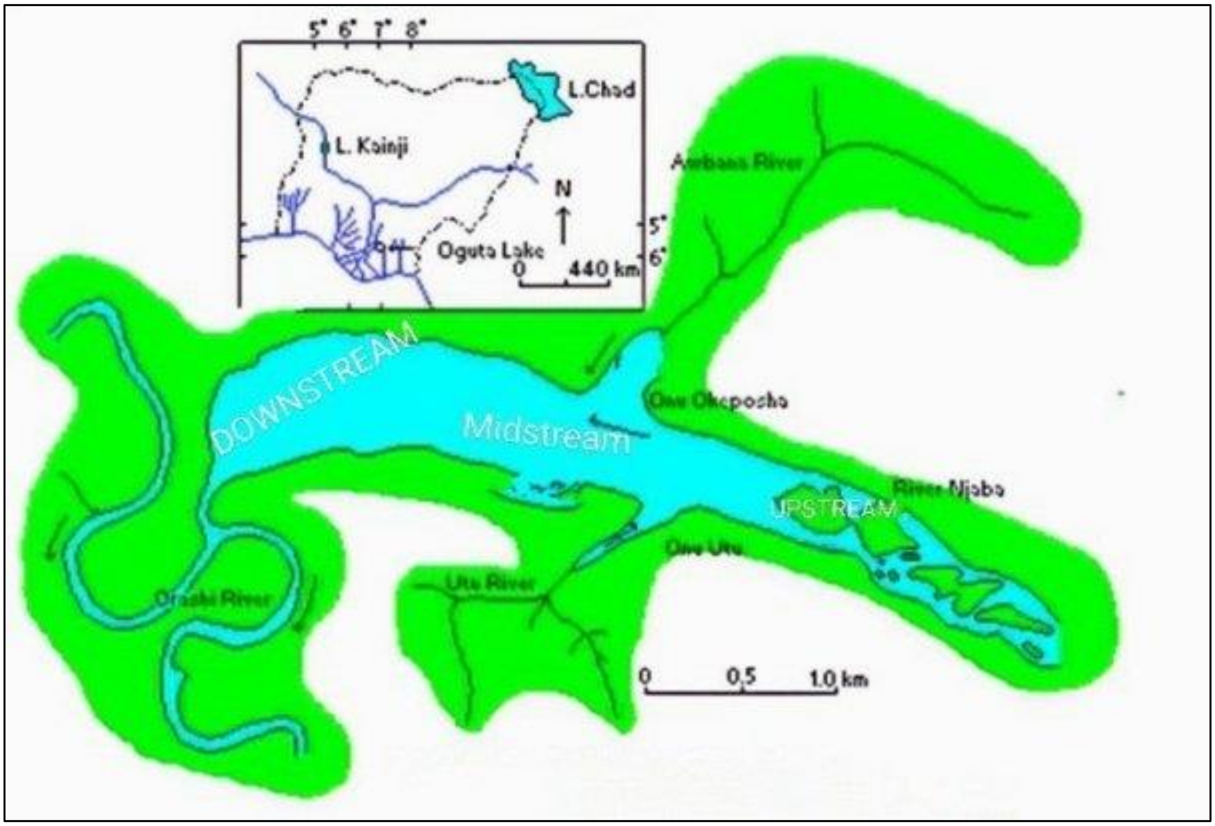

Fig. 1. Sketch Map of Oguta Lake Showing the Three Sampling Locations.

The sampling stations for macrophytes, surface water and sediments for the lake are represented in fig. 1. Three sampling stations were mapped with 0.3km between each sampling stations. Upstream is where activities such as, cassava fermentation, farming, bathing take place, the midstream where the jetty for transportation crosses over and the downstream receives water flow from upstream and links to Orashi river. Fishing is taking place here. Samples were collected every month from the three sampling stations from June to November 2019 using a motorized boat.

The locations of the sampling stations in terms of latitude and longitude are N 05^{O} 42.039’ E 006^{O} 48.410’ 35ft for upstream, N 05^{O} 42.216’ E 006^{O} 48.801’ 39ft for midstream and N 05^{O} 42.696’ E 006^{O} 48.350’ 30.6ft for downstream.

Sample collection was guided by a standard procedure (APHA, 1998). Before collection, the containers were rinsed three times with water at the sampling sites. Water sampling was done by gently lowering the container into the lake (Ozoko, 2015). Water samples for the trace metal analysis were collected from the lake at the depth of about 0.2 to 0.3 m from the lake surface. All sample bottles containing the water samples were properly labelled and test was conducted on replicate samples.

Sediment samples were collected from the topmost layers (5-7 cm) of deposited sediment at the bottom and put in polythene bags. Sediment samples were transported to the laboratory in polythene bags with necessary precautions. The samples were put at room temperature and air dried and sieved to sample out <60 µm diameter fractions of sediment particles. The samples were homogenized, ground in an agate grinder, and stored at -12 to -15 °C for the next level of analysis.

Samples of *Nymphaea lotus* was first counted to record their distribution before being collected. *Nymphaea lotus* specimens were collected randomly from the three locations. The samples were stored in polythene bags and later transported to the laboratory. On arrival at the laboratory, the samples were washed with distilled water to remove any adhering particles and were further rinsed properly before drying to constant weight in an oven at 80 °C. The samples were ground to fine powder and stored at 15°C for the next level of analysis.

Heavy metal concentrations in both surface water and macrophyte samples was determined by digestion and spectrophotometric quantification. Water and macrophyte samples were done by the wet digestion according to the method by Plank (1992). The digested water and macrophyte samples were subjected to heavy metal analyses using an atomic absorption spectrophotometer. The data quality was ensured using duplicates, blank tests, and standard references.

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The physical parameters determined for water samples were temperature and pH, electrical conductivity was done using standard procedure according to APHA (1998). Heavy metals investigated for sediments and macrophyte samples include mercury, lead, nickel, arsenic, zinc, and chromium.

Data generated were subjected to descriptive statistics and exploratory data analysis. The strength and nature of relationships were determined using Pearson's correlation coefficient and scatter plot using SPSS 28.0.1.0.

III. RESULTS

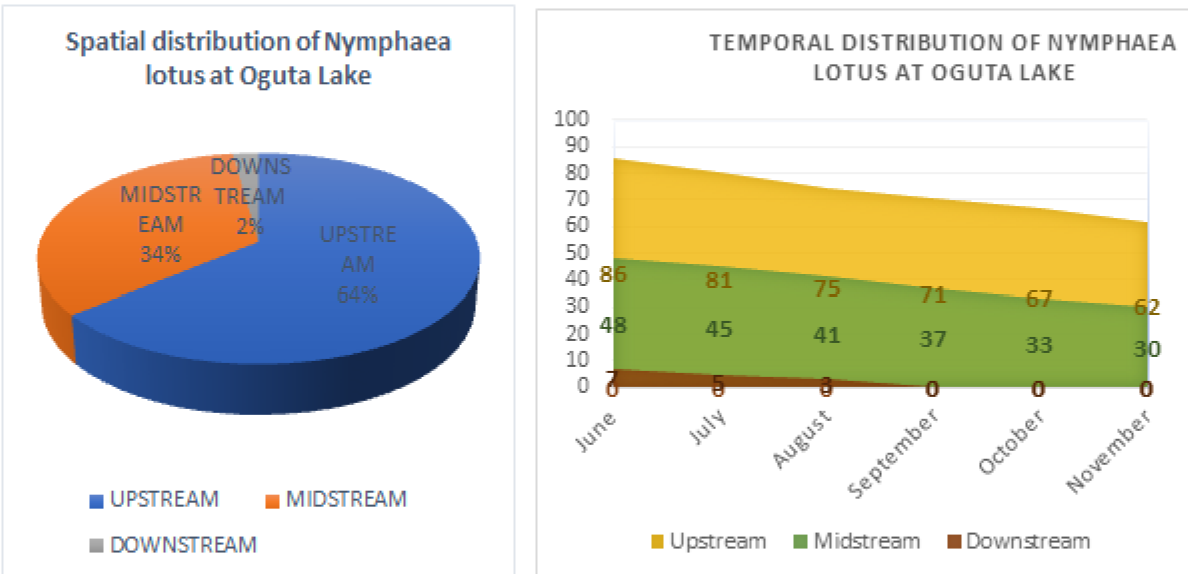

Fig. 2 Distribution of Nymphaea Lotus in Oguta Lake.

The stacked area chart shows how the population of *Nymphaea lotus* in different regions of Oguta Lake (Upstream, Midstream, and Downstream) changes from June to November. The macrophyte population was highest in June across all regions and gradually decreases over time. Upstream had the largest initial population (86) in June and steadily declines to 62 by November. Midstream starts at 48 in June and declines to 30 by November. Downstream has the smallest population, starting at 5 in June and reaching 0 by October. The macrophyte was most abundant upstream throughout the entire period, but its population declines in all regions, particularly in the downstream area, which has the smallest and most rapidly declining population.

The pie chart provides a snapshot of the overall spatial distribution of *Nymphaea lotus* across the lake: Upstream accounts for the largest share of the macrophyte population (64%). Midstream occurs next, with 34% of the total population. Downstream has the smallest share, at only 2%. Most of the *Nymphaea* population is concentrated in the upstream region, followed by a smaller midstream population, with almost no macrophytes downstream. The population of *Nymphaea lotus* declined over time from June to November in all regions, with the largest decrease occurring downstream. This could be attributed to the sample collected for heavy metal analysis and other environmental disturbances. Spatially, the upstream area has the highest concentration of macrophytes (64%), while the downstream area has the lowest (2%), suggesting that environmental or ecological conditions upstream are more favourable for the macrophyte.

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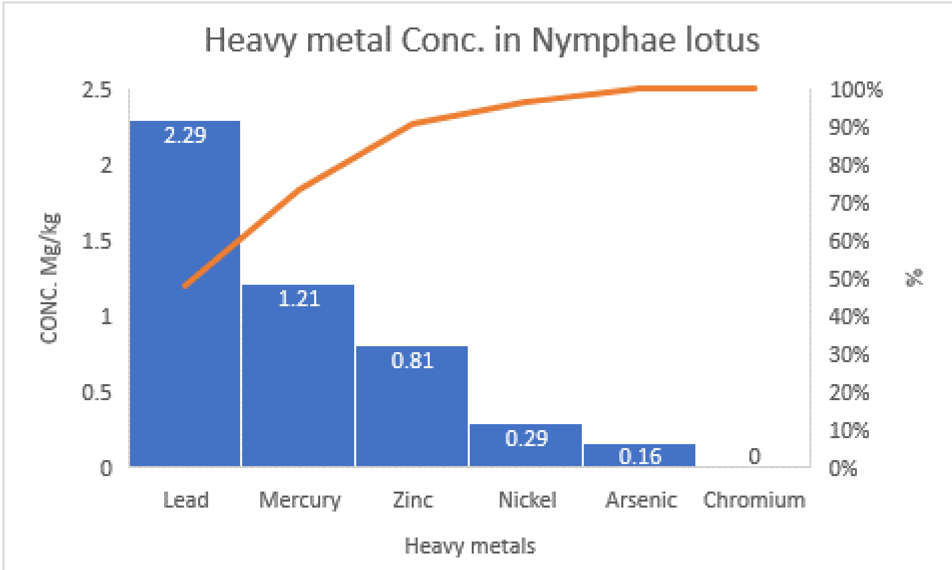

Fig, 3: Concentrations of Heavy Metal Absorbed by Nymphaea Lotus from Sediments and Surface Water

Lead, mercury, and zinc are the metals that *Nymphaea lotus* shows a high affinity for, accumulating higher concentrations than those present in sediments and water. Nickel is absorbed but at lower levels, showing moderate selectivity. Arsenic is poorly absorbed, and macrophytes show little accumulation relative to its availability in the environment. Chromium was not absorbed at all, as indicated by the zero concentration in the macrophyte. This may be due to the form in which chromium exists in water, or it may be selectively excluding it. Because sediments also have no chromium, the macrophyte may not encounter bioavailable chromium forms in its immediate environment. The macrophyte *Nymphaea lotus* selectively absorbs certain heavy metals, particularly lead, mercury, and zinc, while it excludes or inefficiently absorb arsenic and chromium. This selective absorption pattern could be due to the macrophyte's biological mechanisms that favor the uptake of certain metals over others based on their bioavailability, form, or chemical affinity. This agrees with Usman and Abdus-Salam, (2011) who recorded aquatic macrophyte absorbing lead and zinc more than other heavy metals.

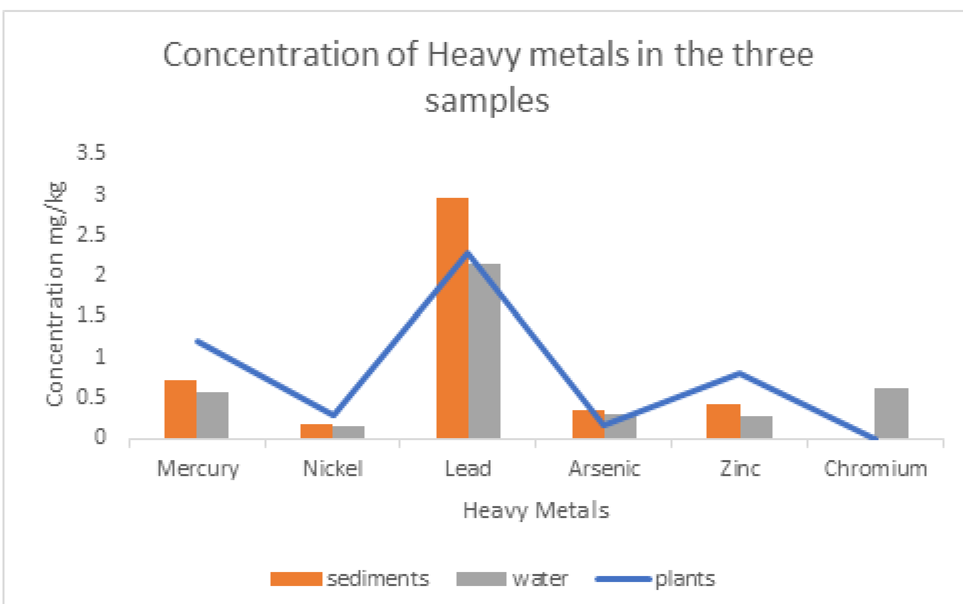

Fig. 4: Concentrations of Heavy Metals Across the three Samples Investigated.

Figure 4 highlights how different metals distribute across the three environmental samples (Sediments, surface water, and *Nymphaea lotus*). Water has a more consistent and lower concentration of metals, except for an outlier caused by lead. Lead was consistently the highest metal across all three samples, showing a remarkably high concentration in both sediments (2.96mg/kg) and *Nymphaea lotus* (2.29 mg/kg) and remained high at 2.16 mg/l in water. The high Lead concentrations observed in this study can be from the fuel from the boats and ferry that transfer automobiles across the lake as there are no bridges. The concentration of mercury was moderate (0.72 mg/kg) in sediments, with concentration in water (0.57mg/l), slightly lower than in the sediments. The concentration of mercury in *Nymphaea lotus* is higher than in sediments and surface water. Nickel concentrations are low across all three samples, with *Nymphaea lotus* being slightly higher than sediment and water (0.29 mg/kg). Lower concentrations of arsenic and zinc is observed in this experiment with *Nymphaea lotus* showing tendency toward selective absorption; having higher concentration of zinc than in sediments and water sample, and arsenic not as accumulated in *Nymphaea lotus* compared to sediments and water. Chromium was not detected in both macrophytes and sediment and was at low concentration (0.62 mg/kg) in water. Water tended to have the lowest concentrations overall, except for chromium, which is only present in water. The concentrations of metals in macrophytes are higher and more variable than those in water, with sediments somewhere in between.

Table 1: Heavy Metal Conc. with Standard Limit for Surface Water

Heavy Metal	Level in surface water in Oguta Lake (Mg/L)	WHO Limit (Mg/L)
Nickel	0.16	0.07
Chromium	0.62	0.05
Lead	2.16	0.01
Mercury	0.57	0.006
Arsenic	0.32	0.01
Zinc	0.28	-

All the heavy metals investigated in this study were far above the WHO permissible limits (Table 1), except for zinc, which has no specific health-based guideline (However, 3 mg/L is often used as a taste threshold, and some countries adopt this as a limit for aesthetic quality). This is in contrast with some previous studies at Oguta Lake (Umunnakwe & Aharanwa, 2014; Egereonu et al. 2015; Ogunfowokan et al. 2013; Emele et al. 2021; Atawal Andong et al. 2019; Madu et al. 2022), although this study revealed the pollution status of the stream as of the time of sampling. The surface water temperature of the lake ranges from 24^0c to 30^0c.

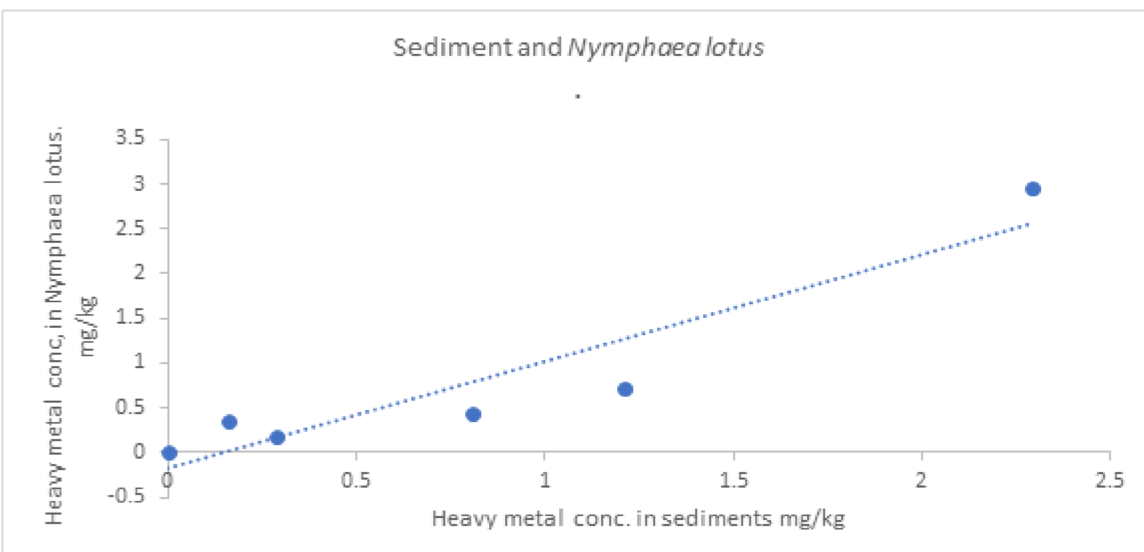

Fig 5: Scatter Plot Showing the Relationship between Metal Concentration in the in Sediment and Macrophyte Samples.

The scatter plot demonstrates a strong positive linear relationship between *Nymphaea lotus* and sediment measurements, as evidenced by the Pearson correlation coefficient of 0.936. This suggests that the metal concentrations in sediments directly affect the amount of metal absorbed by macrophytes. The data points show a linear trend, indicating that *Nymphaea lotus* absorbs metals in proportion to their presence in sediments. This can be evidenced in Lead (2.96 mg/kg in sediments and 2.29 mg/kg in *Nymphaea lotus*), which shows strong absorption from sediments to *Nymphaea*. Similarly, mercury and zinc followed this pattern. This correlation suggests that *Nymphaea lotus* absorbs metals directly from the sediments. The higher the metal concentration in the sediment, the more the *Nymphae* absorbed it. This implies that sediments could be the key source of metal uptake by aquatic macrophytes.

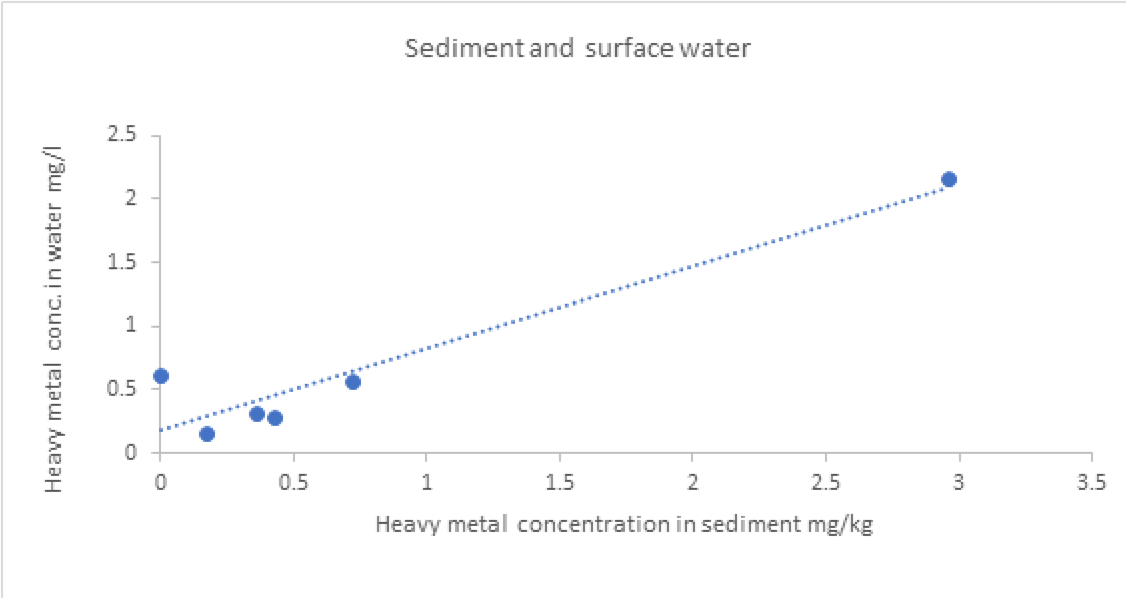

Fig. 6: Scatter Plot Showing the Relationship between the Metal Concentration in the Sediment and the Surfacee Water.

The high correlation coefficient of 0.951 suggests a strong positive correlation between the concentrations of heavy metals in sediments and water. This means that when metal concentrations are high in sediments, they are also high in water, and vice versa. Fig. 6 showed that the points follow a near-linear trend, showing that the metals present in sediments are found in water at corresponding levels. For example, lead has the highest concentration in both sediments (2.96 mg/kg) and water (2.16 mg/L), and similarly, zinc showed proportional relationship (0.43 in sediments, 0.28 in water. This correlation indicates that the metals in the sediments are likely leaching or influencing the metal concentrations in the water. As sediments act as reservoirs for metals, they affect metal levels in water.

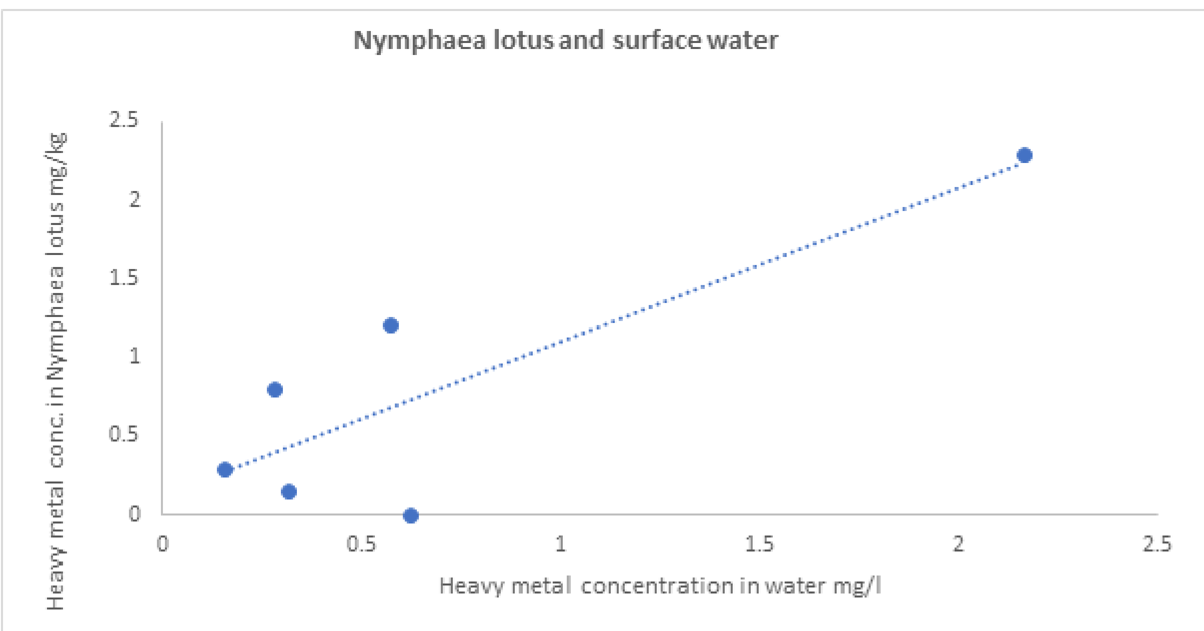

Fig. 7: Scatter plot Showing the Relationship between the Metal Concentration in Nymphaea Lotus and Surface Water.

The correlation coefficient of 0.845 was strong but slightly lower than the others, indicating a strong positive correlation between metal concentrations in *Nymphaea lotus* and water, but with some variation. Fig. 7 shows a linear relationship, but the points are a bit scattered compared to the previous plots, indicating some variability in the amount of

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metal *Nymphaea lotus* absorbs from water. For example, chromium is present in water (0.62 mg/L) but absent in macrophytes (0 mg/L), causing some deviation from the trend. The relationship suggests that while macrophytes absorb metals from water, other factors influence their absorption, such as the bioavailability of the metals or the specific affinity of macrophytes for certain metals. For instance, chromium is present in water but not in macrophytes, showing selective absorption.

Some of the heavy metals investigated in this study tended to have higher concentrations in *Nymphaea lotus* when their concentration is also high in sediments. This suggests that *Nymphaea lotus* takes up heavy metal more from sediments than from water. And lays credence to Vardanyan and Ingole (2006) and Sawidis et al (1995) who recorded that the accumulationn of most of the heavy metals in some macrophytes studied was higher in root system. Sediments showed the highest concentrations of most metals (especially lead), which could indicate they serve as a sink for metal accumulation. *Nymphaea lotus* accumulates more mercury, lead, and zinc, than other metal investigated, possibly because these metals are more bioavailable or easier for macrophytes to absorb. Most heavy metals are toxic their exact toxicity varies considerably. All toxic heavy metals can endanger human health on slight exposure and the consumption of *Nymphaea lotus* should be discouraged due to this bioaccumulation.

Correlation analysis showed strong correlation across all sample types. The high correlation values between sediment-water, sediment-macrophyte, and macrophyte-water indicate a consistent interaction among these three environmental samples for heavy metal concentrations. The strong correlations between sediments and both *Nymphaea lotus* and water (0.936 and 0.951respectively) suggests that sediments are the primary source of metals, influencing both water quality and macrophyte absorption. While the macrophyte-water correlation was strong (0.845), it is slightly less consistent, possibly due to selective metal uptake by macrophytes (as seen with chromium) or other environmental factors affecting metal availability in water compared to sediments.

IV. CONCLUSION

The present study revealed that the aquatic macrophyte, *Nymphaea lotus* is sparsely populated in the Oguta Lake and plays a significant role in reducing the high concentration of some heavy metals, therefore, can be used as a tool for bioremediation. This study also revealed that Oguta lake is heavily polluted with heavy metals and is not suitable for domestic use. Corrective measures, such as introducing more *Nymphaea lotus* into the lake is suggested. After a short growth period, the *Nymphaea lotus* should be harvested and properly disposed of to prevent overgrowth of the plants, which could disrupt the lake's natural ecosystem balance. Regular harvesting ensures that plants do not become invasive while maintaining their role in pollutant removal. To prevent further contamination, it is essential to control both point and nonpoint sources of heavy metal pollution by identifying and mitigating discharges or runoff that directly release heavy metals into the lake and implementing better land management practices.

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