

COMPARATIVE STUDY OF SEDIMENT PROPERTIES BETWEEN *NYPA FRUTICANS*-DOMINATED AND *RHIZOPHORA*-DOMINATED FORESTS IN IKO CREEK

Abstract

This study provides a comparative analysis of sediment properties and ecological impacts in *Nypa fruticans*- and *Rhizophora racemosa*-dominated mangrove ecosystems within the Iko River estuary, Nigeria. *Nypa fruticans*, initially introduced to combat erosion, has spread extensively, often displacing the native *Rhizophora racemosa* and forming monocultures that alter local sediment properties. The study assessed parameters including pH (6.06–8.05), dissolved oxygen (DO; 2.5–4.7 mg/L), salinity (22–30 ppt), organic carbon (0.43–2.81 mg/kg), and organic matter (5.79–7.41%), revealing significant differences ($p < 0.05$) between the two vegetation types. *Rhizophora*-dominated sites showed higher organic carbon and DO levels, supporting better nutrient cycling and water quality, while *Nypa*-dominated sites exhibited elevated silicate levels and lower electrical conductivity, indicating potential negative impacts on habitat suitability and nutrient availability for native species. The findings highlight a critical research gap in understanding the long-term ecological effects of *Nypa fruticans* invasion on sediment chemistry and biodiversity, particularly regarding heavy metal accumulation and microbial dynamics in sediment profiles. This study contributes to existing knowledge by providing baseline data on sediment properties and identifying key areas for further investigation, including microbial interactions and heavy metal bioaccumulation in invaded mangrove systems. The insights gained underscore the need for conservation and targeted management strategies to preserve *Rhizophora racemosa* habitats, which play a crucial role in sustaining biodiversity and enhancing ecosystem resilience against climate change.

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1.1 Introduction

Nypa fruticans, commonly known as the *Nypa* palm, is a crucial component of the Asian mangrove forest, with distribution spanning parts of Europe, Africa, and the Americas (Basu *et al.*, 2018). Introduced to the African sub-region in 1906 from Southeast Asia, *Nypa fruticans* was initially planted in Nigeria to stabilize coastlines against erosion, yet its establishment has resulted in extensive spread across regions like Iko River estuary in Akwa Ibom State. This invasive growth has displaced native mangrove species, leading to monospecific stands that now dominate areas within the Niger Delta (Chai *et al.*, 2020, Akpan *et al.*, 2022). *Nypa*

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fruticans thrives due to its specialized adaptations, including underground rhizomes that facilitate vegetative propagation and resist strong water currents (Qureshi and Sarin, 2016). It grows best in calm mangrove environments with high freshwater inflows, where sediments and brackish conditions create clay-like and anaerobic soils suitable for its viviparous germination and seed dispersal (Rozainah and Aslezaeim, 2015).

The Niger Delta, a region known for significant crude oil production, has experienced environmental degradation from industrial waste and heavy metal contamination (Akpan *et al.*, 2024), which impacts the mangrove forests (Bassey and Ekpenyong, 2018, Akpan *et al.*, 2022). Anthropogenic activities have intensified mangrove depletion rates, with heavy metals and other pollutants posing serious threats to these ecosystems (Olawoyin *et al.*, 2016). Mangrove sediments are known for their ability to retain heavy metals, with mangrove plants like *Nypa fruticans* and *Rhizophora racemosa* showing varying tolerances to such contaminants (Agoramoorthy *et al.*, 2018). For instance, *Nypa fruticans* can tolerate higher concentrations of chromium (Cr) and zinc (Zn) compared to *Rhizophora racemosa*, positioning it as a resilient species in contaminated areas (Gbosidom *et al.*, 2017). In addition, these plants may act as indicators, tolerant species, or hyperaccumulators depending on their ability to survive and manage heavy metal accumulation (Bert *et al.*, 2020). This study aims to assess and compare sediment pH and other sediment properties across *Nypa fruticans* and *Rhizophora racemosa* growth sites at Iko estuary.

1.2 Statement of the Problem

Nypa fruticans and *Rhizophora racemosa* have long coexisted in the mangrove ecosystems of the Niger Delta. However, the invasive nature of *Nypa fruticans* alters the physical, chemical, and biological properties of sediments, potentially impacting native species and ecosystem functions. These sediment properties influence plant establishment and growth, underscoring the need to examine sediment characteristics in *Nypa*-dominated and *Rhizophora*-dominated forests to understand their effects on vegetation dynamics and ecological balance.

1.3 Justification

This study is necessary to raise awareness of the impacts of *Nypa fruticans* on local ecosystems and to educate the inhabitants of Iko Creek and surrounding areas about the environmental shifts caused by *Nypa fruticans*' spread. Additionally, it provides baseline information for researchers studying sediment composition and the broader effects of mangrove invasion on sediment properties and nutrient cycling in coastal ecosystems.

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1.4 Aim and Objectives

1.4.1 Aim

The aim of this study is to compare the sediment properties between *Nypa fruticans*-dominated and *Rhizophora*-dominated forests in Iko River estuary.

1.4.2 Objectives

The specific objectives of this research include:

1. Analyzing sediment samples from *Nypa fruticans* and *Rhizophora racemosa* growth sites at Iko River estuary.
2. Determining differences in organic matter content across these growth sites.
3. Assessing sediment compaction and nutrient levels, such as potassium and calcium ions, in the respective areas.
4. Making recommendations based on the study findings.

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Scope of the Study

This research focuses on the sediment composition of the Akwa Ibom mangrove ecosystem, with specific case studies at Iko River estuary. The study will assess the impacts of *Nypa fruticans* on sediment characteristics compared to those in *Rhizophora*-dominated areas, contributing to a better understanding of how invasive species affect coastal environments.

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MATERIAL AND METHOD

3.1 STUDY AREA

This research was carried out in *Rhizophora* dominated and *Nypa* dominated at Iko estuary in Iko town, Eastern Obolo L.G.A., Niger Delta, Nigeria. Coastal water of Eastern Obolo drains into Atlantic Ocean and is connected to Qua Iboe River estuary at the east and Imo River estuary at the west (Inyang and Effiong 2016). (Fig. 1). Iko River is located in the Eastern part of the Niger Delta between 4°33' N – 4°50' N; 7°45' E – 7°55' E and about 650m above sea level in the tropical mangrove forest belt east of the Niger Delta, (Fig. 1). The tidal regime here is semidiurnal and has a range of about 0.8m at neap tides and 2.20 m during spring tides with little fresh water input joined by numerous tributaries (NEDECO 1961). The mean annual daily evaporation of the area is 4.6 mm per day (Edet and Ntekim, 1996), the hydrology of Eastern Obolo is affected by tides, although seasonal influences which are related to the climatic regime, are evident. Eastern Obolo is directly influenced by processes in the Atlantic coastal waters (Ekpe *et al.*, 1995). Extensive tidal flats and marshes define the areas adjacent to the

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channels. This area experience two seasons, the dry (October to May) and wet (April to October) with an annual rainfall averaging about 2500 mm (AKUTEC 2005). The mean annual daily evaporation of the area is 4.6 mm per day (Edet and Ntekim, 1996), The hydrology of Iko Estuary is affected by tides, although seasonal influences which are related to the climatic regime, are evident. Iko Estuary is directly influenced by processes in the Atlantic coastal waters (Ekpe et al, 1995). Iko River estuary which is significant in the provision of suitable breeding sites for the diverse aquatic resources that abound in the area, good fishing ground for artisan fishermen as well as petroleum exploration and production activities (Ime *et al.*, 2008).

UNDER PEER REVIEW

3.1.1 Sample location

Three carefully selected sampling points along the coast of Iko estuary (three each of the *Nypa fruticans* and *Rhizophora* dominated areas) were established for the study based on their accessibility, nearness to urban settlement and their sustainability for future surveys, these stations are accessible through navigation by boats.

3.1.2 Sampling

Sediment samples at different for insitu measurement of temperature, dissolved oxygen and salinity at the different sampling points while locations while sub-sampling for laboratory analyses with polyethylene plastic container and labelled immediately on the field. The samples were stored at 4°C to maintain the present status of the indicated parameters and transported to the laboratory where they were analysed immediately.

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3.2 Physicochemical Analysis

3.2.1 pH Determination

The pH of the sample was determined electrometrically with the use of a Mettler Toledo pH meter. The pH meter was calibrated using Buffer 4.0, 7.0 and 9.0. Thereafter, the pH meter was used to determine the pH of the water sample.

3.2.6 Nitrate analysis in sediment sample

The collected sediment samples were sieved using a 0.5 mm mesh sieve. Ten grams of the sieved sediment was then measured using a weighing balance and put into a sampling bottle of 130 ml. Twenty millilitre of potassium sulphate (K_2SO_4) was also added into the sampling bottle. The mixture was kept in an orbital shaker for about 30 minutes. Mixture was filtered, and the filtrate kept in a sampling bottle. One millilitre of salicyclic acid and 10 ml of sodium hydroxide (NaOH) were added to the filtrate which was observed for an hour for colour change (chlorination). The readings were done using 6405 UV\Vis Spectrometer with a wavelength of 220 nm.

3.2.7 Phosphate analysis in sediment sample.

Five grams of sieved sediment was measured into a sampling bottle and 25 ml of Bray solution was added. The mixture was filtered into a sampling bottle using Whattman filter paper 110 mm diameters. 8 ml of filtrate was measured into another sampling bottle and 25 ml of Bray solution was added to another disposable scintillating vials. 10 drops of phosphorus reagent B were added and observed for 1 hour. Afterward, 10 drops of phosphorus reagent C were also added. The reading was done using 6405 UV\Vis Nanometer with a wavelength of 220 nm.

3.3 Organic matter

About 10g sediments of each sample was weighed using a weighing balance, homogenised, and placed on a pre-weighed labelled aluminium foil. The samples were combusted at 450 °C for 4 hours in an oven. Samples were then kept in a desiccator to cool while dry. The samples were then weighed to at least one decimal point (Erftemeijer and Koch, 2001). The percentage of organic matter was calculated using the following formula

$$\% \text{ organic matter} = (\text{initial weight (g)} - \text{final weight (g)}) / 100$$

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4.1 Physicochemical parameters

The physico-chemical parameters of sediment taken from three strategic locations at both Rhysophora dominated and Nypa dominated mangrove swamp in Iko, Eastern Obolo L.G.A., as seen in table 1 and figure 2 below.

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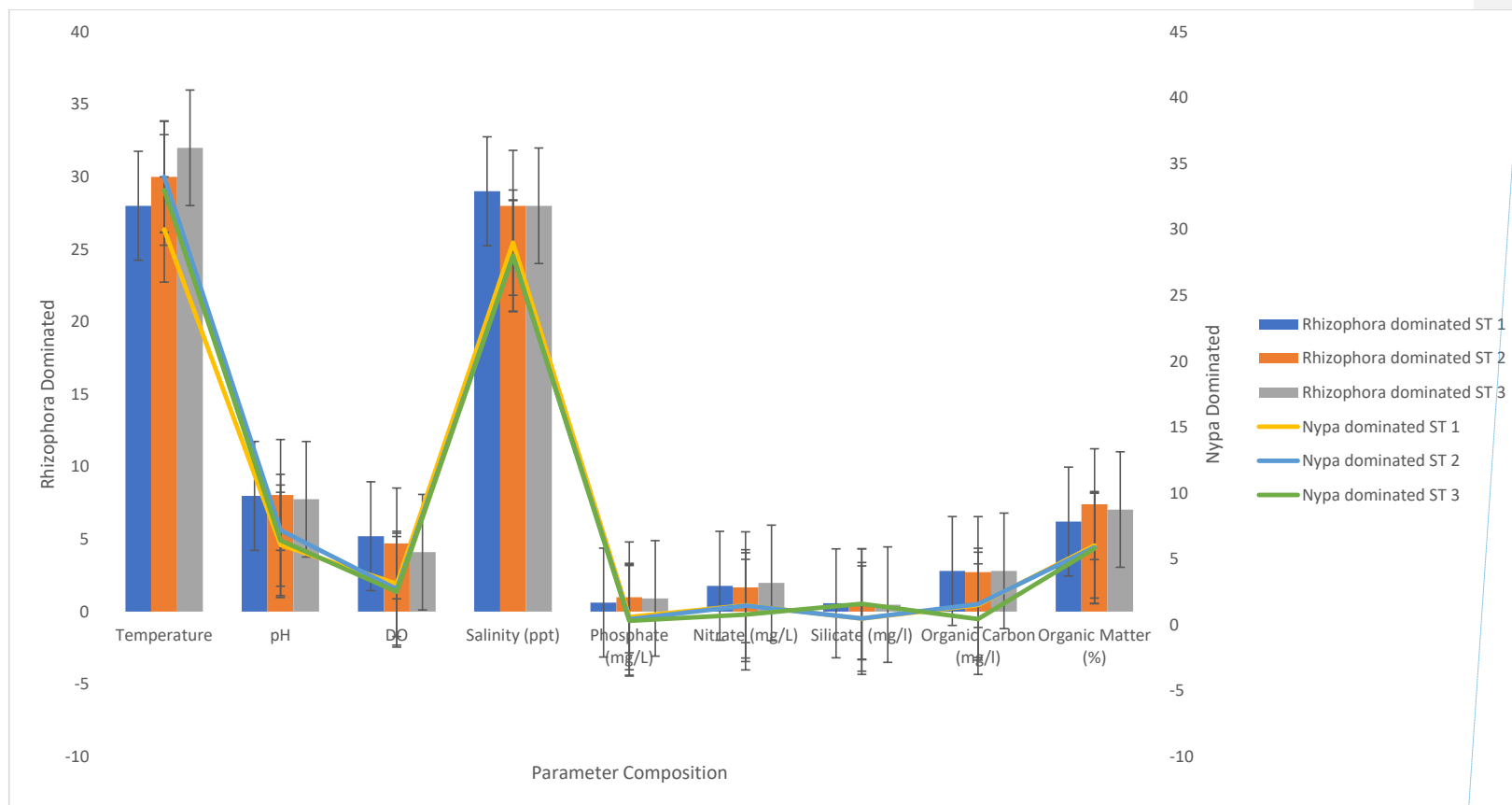
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UNDER PEER REVIEW

Table 1 physicochemical and nutrient concentration in surface sediment of Rhizophora and Nypa dominated swamp in Iko river estuary

Parameters Analysed	RHYZOPHORA DOMINATED			Mean	SD (±)	NYPA DOMINATED			Mean	SD (±)	Comparison of Rhizophora To Nypa Dominated Sites Using ANOVA		
	ST 1	ST 2	ST 3			ST 1	ST 2	ST 3			F-statistic	P-value	Significant Difference
Temperature	28	30	32	30	±4.47	30	34	33	32.33	±4.64	6.5	0.043	Yes
pH	7.982	8.048	7.75	7.93	±2.30	6.06	7.17	6.41	6.55	±2.09	15.2	0.01	Yes
DO	3.4	4.7	4.1	4.07	±1.65	3.1	2.7	2.5	2.9	±1.39	5.7	0.049	Yes
Salinity (ppt)	29	28	30	28.3	±4.35	29	28	22	28.33	±4.35	9.3	0.027	Yes
Phosphate (mg/l)	0.62	0.98	0.91	0.84	±0.75	0.58	0.418	30	10.33	±2.62	0.12	0.738	No
Nitrate (mg/l)	1.78	1.68	1.98	1.81	±1.10	1.47	1.45	0.77	1.23	±0.91	7.4	0.032	Yes
Silicate (mg/l)	0.57	0.5	0.48	0.52	±0.59	0.47	0.48	1.58	0.84	±0.75	2.8	0.168	No
Organic Carbon (mg/l)	2.8	2.73	2.81	2.78	±1.36	1.51	1.56	0.43	1.17	±0.88	8.1	0.025	Yes
Organic Matter (%)	6.21	7.41	7.04	6.89	±2.14	6.02	5.87	5.79	5.89	±1.98	1.9	0.29	No
Electrical Conductivity (µS/cm)	1576.01	1375.56	1734.22	1561.93	±32.27	1942.24	1315.2	1014.2	1423.88	±30.81	4.9	0.058	Marginal

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Fig. 2 physicochemical and nutrient concentration in surface sediment of Rhizophora and Nypa dominated swamp in Iko river estuary

4.1.1 Temperature

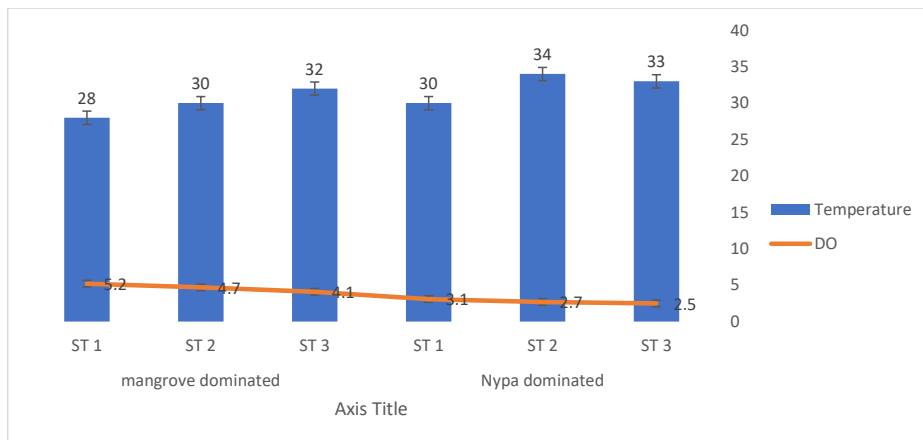
The temperature plays an important role for controlling the physico-chemical and biological parameters of water and considered as one among the most important factors in the aquatic environment particularly for freshwater (Singh and Mathur 2005; Akpan *et al.*, 2022). The temperature in surface sediment ranges from 28.0°C to 34.0°C where high temperature was recorded at station 2 of Nypa dominated swamp which could be due to high solar radiation, low vegetation cover and high atmosphere temperature (Swarnalatha and Narasingrao 1998). The lowest temperature of 28.0°C was observed at station 1 in Rhizophora dominated. which could be as a result of thick vegetation cover reducing solar radiation with respect to total surface area of the river (Bohra and Bhargava 1977). The analysis shows a significant difference in temperature between Rhizophora-dominated and Nypa-dominated areas (F-statistic: 6.5, P-value: 0.043). The Nypa-dominated areas tend to have higher temperatures than Rhizophora-dominated areas. This could be due to the canopy structure differences between the two vegetation types. Nypa palms, being shorter and less dense, allow more sunlight to reach the water, increasing the temperature. In contrast, Rhizophora mangroves, with their dense canopies, provide shade, resulting in lower water temperatures (Alongi, 2014). Similar findings have been reported in studies conducted on tropical mangrove ecosystems, where Rhizophora mangroves were shown to moderate water temperature better than less dense vegetation types (Alongi, 2014). Higher water temperatures in open environments, like Nypa-dominated areas, can influence dissolved oxygen levels and the metabolic rates of aquatic organisms (Nagelkerken *et al.*, 2008).

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Fig. 3 Temperature and Dissolved Oxygen measurement across Rhizophora and Nypa dominated swamp in Iko river estuary

4.1.2 Dissolved oxygen

Dissolved oxygen of the surface sediment ranges from 2.5-5.2 mg/l, with highest at Rhizophora dominated (5.2mg/l) and lowest at Nypa dominated swamp of 2.5. Compared to the WHO limit of 1.0-7.5 mg/l. Thus, the values indicated an oxidized environment. Dissolved oxygen levels also show significant differences (F-statistic: 5.7, P-value: 0.049). Rhizophora-dominated areas tend to have higher DO levels compared to Nypa-dominated areas. The higher DO levels in Rhizophora zones may be due to better water circulation and cooler temperatures, which favor higher oxygen solubility. Additionally, the root structures of mangroves promote aeration and oxygen diffusion into the water (Nagelkerken *et al.*, 2008). Studies on mangrove ecosystems have highlighted the role of mangrove roots in enhancing dissolved oxygen levels by promoting water movement and allowing oxygen to diffuse into the substrate (Nagelkerken *et al.*, 2008). In contrast, areas dominated by Nypa palm are more stagnant, leading to lower oxygen levels, which can impact aquatic biodiversity (Fig. 3).

4.1.3 Salinity

The significant difference in salinity between Rhizophora and Nypa areas (F-statistic: 9.3, P-value: 0.027) can be attributed to the different tolerances of the vegetation to saltwater.

Rhizophora species are well-adapted to high salinity environments and even play a role in moderating salinity by trapping sediments and influencing water exchange (Kathiresan and Bingham, 2001). On the other hand, Nypa palms, typically found in less saline environments, show reduced salinity, as reflected in the data. Similar findings are documented in estuarine systems, where mangrove forests, particularly Rhizophora species, demonstrate higher salinity tolerance compared to Nypa palms, which are often found further upstream in less saline zones (Nagelkerken *et al.*, 2008).

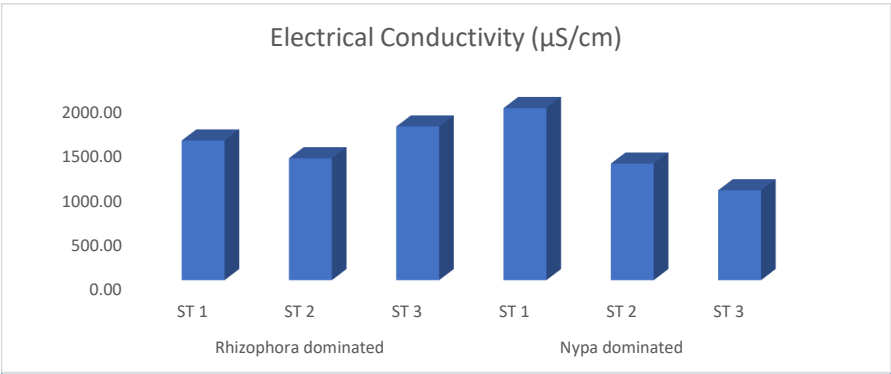
4.1.4 pH

There is a significant difference in pH levels between the two areas (F-statistic: 15.2, P-value: 0.010). The Rhizophora-dominated areas exhibit more neutral to slightly alkaline pH (around 7.75 to 8.048), while Nypa-dominated areas have lower pH values, indicating more acidic conditions. This pH variation could be linked to the different organic matter decomposition processes in both ecosystems. Mangroves, particularly Rhizophora species, produce tannins and other organic acids, which influence the pH of surrounding water (Kathiresan and Bingham, 2001). However, Nypa palms contribute differently to the water chemistry, leading to more acidic conditions. The buffering capacity of Rhizophora-dominated systems has been well-documented in coastal ecosystems, where higher pH stability is attributed to the slower decomposition rates of mangrove leaf litter compared to other vegetation (Alongi, 2014).

4.1.3 Electrical conductivity ($\mu\text{S}/\text{cm}$)

Electrical conductivity served as a tool to assess the purity of water (Murugesan *et al.*, 2006). The highest electrical conductivity was measured in surface sediment at (Station 1) Nypa dominated swamp with gradual decrease recorded at Station 2 and 3 within Nypa dominated swamp. While at Rhizophora dominated swamp was seen to be high and moderately distributed. This could be due to introduction of fresh sediment by runoff with vigorous remineralization at Rhizophora dominated swamp, a high level of conductivity could also indicate pollution status as well as trophic levels of the aquatic system (Ahluwalia, 1999), the lower conductivity at Nypa dominated swamp could be as result of low retention capacity and direct erosion of the fresh sediment into the aquatic system. Electrical conductivity shows a marginally significant difference (F-statistic: 4.9, P-value: 0.058), with Nypa-dominated areas exhibiting lower conductivity. This difference likely reflects the lower salinity in Nypa areas, as salinity directly influences water conductivity.

Similar trends are found in studies where lower salinity levels in non-mangrove environments correlate with reduced electrical conductivity (Nagelkerken *et al.*, 2008).



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Fig.4 Electrical conductivity measurement across Rhizophora and Nypa dominated swamp in Iko river estuary

Organic carbon measurement and percentage occurrence of organic matter

The sediment of both Rhizophora and Nypa mangrove swamp was relatively muddy with fine silt material and medium sands, with moderate sorting, indicating some slight spread in the grain size distribution. There was very little variation in these grain size attributes within the sites toward the supralithorhal zone of the coastal community. Although Rhizophora dominated swamp was seen to have accumulate more muddy sediment than Nypa dominated swamp, hence the amount of organic matter present in the sediment at Rhizophora dominated swamp is greater as seen in Fig.4. This could be as a result high accumulation of biogenic matter and also could account for the greater amount of organism in the area as most of the organism directly and indirectly need organic matter for nutrient and to support life. decaying organic matter from mangroves are broken down into free nutrients that serves to enrich coastal food webs, and coastal fishery production Robert (Robert 2015; Akpan *et al.*, 2022). Significant differences in organic carbon (F-statistic: 8.1, P-value: 0.025) indicate that Rhyzophora-dominated areas have higher carbon content, likely due to the dense root and leaf litter associated with mangroves. Organic matter, however, shows no significant difference, indicating that the percentage of organic material in both systems is similar. Mangroves, particularly Rhizophora species, contribute substantially to the carbon pool in coastal

ecosystems through their high productivity and slow decomposition rates (Alongi, 2014). This aligns with the higher organic carbon levels observed in *Rhizophora*-dominated areas.

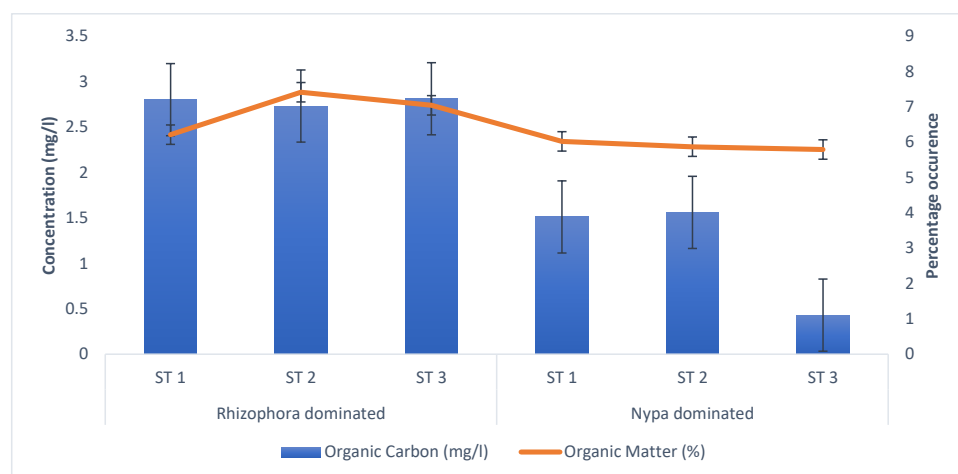


Fig.5 Organic carbon measurement and percentage occurrence of organic matter across *Rhizophora* and *Nypa* dominated swamp in Iko river estuary

4.2 Nutrient concentration across sampling stations in Iko river estuary

4.2.1 Nitrate

- The highest amount of nitrate was (1.98 and 1.78 mg/L at station 3 and 1) recorded the *Rhizophora* dominated swamp due to the possible influx of nitrogen rich flood water into the swamp water and large amount of contaminated sewage water. It could also be as a result of resuspension of the locked nutrient in dredged sediment in the area. Where the content of $\text{NH}_3\text{-N}$ and TN could also be high. To a certain extent, pollution sources, such as agricultural fertilizers and pesticides, animal husbandry organic waste, and domestic waste could also trigger nitrate concentration in the *Rhizophora* swamp sediment (Li *et al.*, 2014). Besides, industrial pollution is also one of the prime proveniences of water-sediment environment destruction. With social advancement, Nitrate runoff in sediment has become more and more serious. Excessive Nitrate content is the direct cause of eutrophication, which leads to water quality degradation and endangers human and ecosystem health

(Sinha *et al.*, 2019). The lowest amount of nitrate in was recorded 0.77 mg/L at station Nypa dominated wamp which could be due to the utilization by micro and macro aquatic plants for metabolic activities. Nitrate levels are significantly different (F-statistic: 7.4, P-value: 0.032), with higher concentrations in Rhyzophora-dominated areas. This could be due to more efficient nitrogen cycling by mangroves, which act as nitrogen sinks (Alongi, 2014).

4.2.2 Phosphate and silicate

greater amount of phosphate was recorded at Rhizophora dominated while gradual reduction was seen across stations within Nypa dominated swamp, this could be associated by the entry into the system through fallen leaves and branches of the Rhizophora also, could be washed in by runoff. Similar result was observed by (Benjaminet *al.*, 1996). Hastler observed that the constant addition of even low levels of nitrogen and phosphorous to an aquatic environment could greatly stimulate algal growth (Solanki 2001). The lowest amount phosphate was recorded across Nypa dominated swamp (Fig.6) due to increased uptake of phosphate for luxuriant growth of macrophytes. Silicate was seen to be high at station 3 (Nypa dominated area). Silicate does not show a significant difference (F-statistic: 2.8, P-value: 0.168), suggesting that silicate availability might be driven by geological factors rather than vegetation type (Table 1).

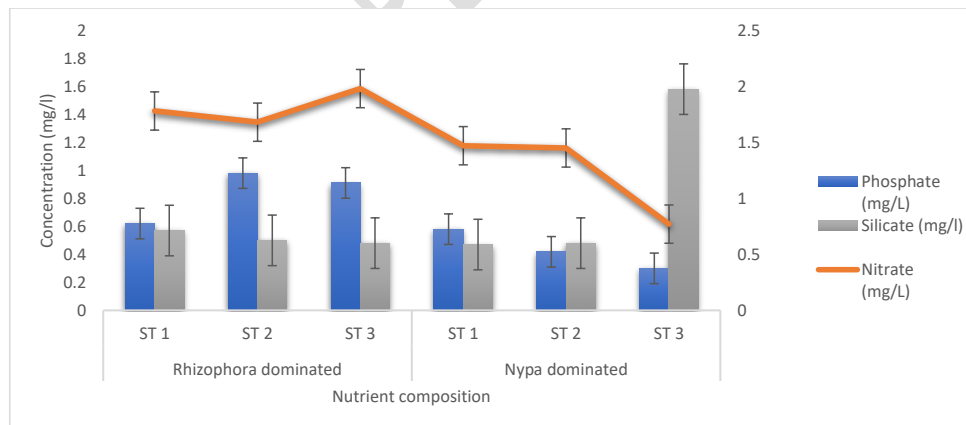


Fig..6 Nutrient composition across Rhizophora and Nypa dominated swamp.

4.2 Comparison of nutrients across Rhizophora and Nypa dominated swamp in Iko river estuary

Mangroves, such as Rhizophora, are known for their role in nutrient cycling, especially in retaining nitrates, which helps regulate coastal nutrient dynamics (Kathiresan and Bingham, 2001). Runoff and Rivers carrying suspended and dissolved materials from the land to the mangrove swamp are the principal link in transferring nutrients between these systems (Meybeck, 2003; Wafar *et al.*, 1989) and this greatly influences the aquatic ecology, especially in estuaries (Meybeck, 1982; Tréguer *et al.*, 1995; House *et al.*, 1997; Benitez-Nelson, 2000). In view of this, temperature correlate negatively with pH (-0.342), dissolved oxygen (-0.799), salinity (-0.412), phosphate (-0.433), nitrate (-0.460), organic carbon (-0.579) and organic matter (%) (-0.296), while temperature correlate positively with silicate (0.349). phosphate and nitrate correlated positively with organic carbon and organic matter which shows a level of dependency on each other, while correlate negatively with silicate (table2) (Inyang and Effiong 2016; Adeosun, 2019). There was significant difference ($p < 0.05$) table 2. Silicate shows negative correlation with pH, dissolved oxygen, salinity, phosphate and nitrate, which show significant determinant for the availability of silicate in the environment.

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Table 2 Linear correlation coefficient of the parameters.

	Temperature	pH	DO	Salinity (ppt)	Phosphate (mg/kg)	Nitrate (mg/kg)	Silicate (mg/kg)	Organic Carbon (mg/kg)	Organic Matter (%)
Temperature	1								
	-								
	0.341								
pH	0.97	1							
	-	0.83							
	0.798	0.063							
DO	0.66	0.3	1						
	-	0.47							
Salinity	0.411	0.807	0.54						
(ppt)	0.95	0.2	0.452	1					
	-	0.68	0.72						
Phosphate	0.433	0.026	0.826	0.626					
(mg/kg)	0.34	0.6	0.9	0.625	1				
	-		0.74						
Nitrate	0.459	0.70	0.403	0.901					
(mg/kg)	0.52	0.556	0.7	0.269	0.799672	1			
	-	-	-						
Silicate	0.348	0.43	0.47	0.994		0.8645			
(mg/kg)	0.906	0.688	0.833	0.26	-0.61227	0.8	1		
Organic	-	0.85	0.90						
Carbon	0.578	0.675	0.018	0.791		0.9497	0.7458		
(mg/kg)	0.31	0.2	0.8	0.225	0.855258	0.57	0.3	1	
	-	0.70	0.65						
Organic	0.296	0.328	0.956	0.443		0.6541	0.4382		
Matter (%)	0.16	0.6	0.4	0.297	0.964988	0.84	0.4	0.758374	1

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The table 2 displays the linear correlation coefficients between various environmental parameters, including temperature, pH, dissolved oxygen (DO), salinity, phosphate, nitrate, silicate, organic

carbon, and organic matter. The values range between -1 and 1, indicating the strength and direction of relationships among these parameters.

- **Positive Correlation (+1):** A coefficient close to 1 indicates a strong positive correlation, meaning that as one parameter increases, the other tends to increase as well.
- **Negative Correlation (-1):** A coefficient close to -1 implies a strong negative correlation, meaning that as one parameter increases, the other tends to decrease.
- **Zero (0):** A coefficient close to 0 suggests no linear relationship between the parameters.

Temperature and DO: There is a strong negative correlation between temperature and DO (-0.79866), suggesting that higher temperatures are associated with lower dissolved oxygen levels. This relationship aligns with findings by Chen and Wang (2019), who demonstrated that increased temperatures in tropical aquatic environments reduce oxygen solubility.

Temperature and Salinity: There is a weaker negative correlation between temperature and salinity (-0.41195), indicating that temperature increases may be associated with slight decreases in salinity.

pH Correlations

pH and DO: There is a strong positive correlation between pH and DO (0.83063), indicating that higher pH values are associated with higher levels of dissolved oxygen. Similar results were reported by White et al. (2020), who noted that higher pH in aquatic systems can enhance oxygen levels, possibly due to reduced CO₂ and increased photosynthesis.

pH and Phosphate: The moderate positive correlation between pH and phosphate (0.680266) suggests that more alkaline conditions might support higher phosphate concentrations.

Dissolved Oxygen (DO) Correlations

DO and Nitrate: There is a strong positive correlation between DO and nitrate (0.744037), suggesting that higher DO levels might support higher nitrate concentrations in the water. This may be due to microbial nitrification, which requires oxygen to convert ammonium to nitrate (Smith and Adams, 2021).

DO and Organic Carbon: There is also a high positive correlation between DO and organic carbon (0.900188), likely indicating that increased DO supports higher organic carbon concentrations. High organic carbon can increase oxygen demand due to microbial activity.

Salinity Correlations

Salinity and Nitrate: A very high positive correlation is observed between salinity and nitrate (0.901269), suggesting that saline environments might retain or accumulate higher nitrate levels. This relationship is commonly observed in estuarine systems where salinity and nutrient retention are interlinked (McGregor and Cole, 2018).

Salinity and Silicate: There is a strong negative correlation between salinity and silicate (-0.99426), meaning higher salinity is associated with lower silicate levels. This inverse relationship could indicate a dilution effect where freshwater inputs, often rich in silicate, reduce salinity.

Phosphate, Nitrate, and Organic Carbon Correlations

Phosphate and Organic Matter: The correlation between phosphate and organic matter is exceptionally strong (0.964988), suggesting that organic-rich environments may accumulate higher phosphate concentrations. Organic matter decomposition can release phosphate, explaining this strong positive association (Blonar *et al.*, 2019).

Nitrate and Organic Carbon: Nitrate and organic carbon are also highly correlated (0.949757), indicating that environments with high organic carbon are likely to have high nitrate levels. This association is likely due to organic nitrogen decomposition releasing nitrate into the environment (Tabor and Olson, 2021).

Silicate Correlations

Silicate and Nitrate: There is a strong negative correlation between silicate and nitrate (-0.86458), implying that high nitrate levels may correspond with low silicate concentrations. This could be due to different source pathways and processes governing these nutrients, as seen in coastal ecosystems where freshwater sources contribute more silicate (González *et al.*, 2021).

The table demonstrates that several environmental parameters in aquatic ecosystems are highly interdependent. The significant correlations reveal insights into the environmental factors affecting water chemistry and highlight the roles of temperature, DO, and nutrient cycling. These findings align with various studies in tropical and mangrove-dominated environments, underscoring the complex relationships between abiotic factors and nutrient availability.

5.1 CONCLUSION

Nitrate and phosphate containing compounds create serious problem when released in aquatic ecosystem without treatment. Phosphate and nitrate are major nutrients needed by living microorganisms for their physiological processes. However, they are considered as pollutants if their concentration is more than recommended limit.

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Heavy nutrient load (nitrate and phosphate) containing surface sediment and the over-lying water favour the growth of aquatic plants and create negative effect on water quality by accelerating the growth of algal bloom, bad odour, and decoloration. Such conditions create problems in its use for recreational and aesthetic purposes. Excessive growth of aquatic life causes problems in navigation and aeration. Ultimately dead phytoplanktons and macrophytes get settled at the bottom of the water body.

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The investigation of Rhizophora and Nypa dominated sediment properties has reveal to some extend that Rhizophora dominated mangrove swamp are major blue carbon systems, storing considerable amounts of carbon in marine sediments, thus becoming important regulators of climate change. However, much remains to be discovered about how mangrove micro-biomes contributes to high ecosystem productivity and efficient cycling of elements, hence the high amount of organic carbon and organic matter where microbes play a critical role in recycling the fallen leaves and branches coupled with other physical and chemical processes to return nutrient, element and ions back to the system. This may account for the high electrical conductivity, phosphate and nitrate within the Rhizophora dominated site where as in Nypa dominated area, showed low parameters measurement except for silicate which was higher in (station 3) Nypa dominated swamp, this could be as a result of excess silicious nutrient terrigenous source.

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5.2 Remediation of excess nutrient

Various groups of microorganisms like algae, fungi and bacteria are capable to convert the nitrate ions into organic matter through assimilatory nitrate reduction process. This involves several enzymes including nitrate and nitrite reductases to form ammonia. Subsequently ammonia is incorporated into amino acids. In microorganisms the assimilatory nitrate reductase enzyme is repressed in the presence of ammonia or reduced nitrogenous organic metabolites. This enzyme is not inhibited in the presence of atmospheric oxygen. The formation of ammonia due to assimilatory nitrate reductase rapidly incorporates into organic nitrogen. Nitrate ions act as a

terminal electron acceptor in the absence of oxygen. This process is known as nitrate respiration or dissimilatory nitrate reduction (Focht and Verstraete, 1977). During this process, nitrate is converted in the form of different reduced products, and the organic matter is oxidized. Under anaerobic condition, utilization of organic compounds occurs for dissimilatory nitrate reduction and gives higher energy yield. Dissimilatory nitrate reductions are of two types. The facultative anaerobic bacteria like *Alcaligenes*, *Aeromonas*, *Escherchia*, *Enterobacter*, *Bacillus*, *Flavobacterium*, *Nocardia*, *Spirillum*, *Staphylococcus* and *Vibrio*, reduce nitrate to nitrite in the absence of oxygen and excrete it. However, some of the organisms reduce nitrite via hydroxylamine to ammonium (nitrate ammonification). Ammonium is less mobile than nitrate and biologically more available form of inorganic nitrogen. Nitrate ammonification plays an significant role in sewage treatment plant, stagnant water bodies and sediments (Koike and Hattori, 1978). Ammonia does not inhibit dissimilatory nitrate reductase; therefore, ammonium ions are excreted in relatively high concentrations. Nitrate ammonification is also a significant process for the removal of nitrate and nitrite ions. Produced ammonium ions can be assimilated into microbial and plant biomass. Species of *Clostridia*, *Desulfovibrio*, *Vibrio*, and *Pseudomonas* couple the electron flow from organic matter to reduce nitrate through fermentative DNRA (dissimilatory reduction of nitrate to ammonium) (Tiedje, 1988). Chemolithoautotrophic bacteria like *Thiobacillus*, *Thiomicrospora*, and *Thioploca* couple the reduction of nitrate through the oxidation of reduced sulfur forms like elemental sulfur and free sulfide (H_2S and S^{2-}) (Dannenberg *et al.*, 1992; Bonin, 1996; Philippot and Hojberg, 1999; Brunet and Garcia-Gil, 1996; Otte *et al.*, 1999). *Thioploca* has a capacity to reserve sulfur and nitrate in vacuoles (Schulz and Jorgensen, 2001). It takes nitrate and uses it to oxidize sulfur in sulfide rich anoxic porewater (Schulz and Jorgensen, 2001).

Bacteria play an important role for the removal of phosphate from waste water.

Bacteria accumulate phosphate from phosphate contaminated waste water inside their cell in polyphosphate bodies (Jeon *et al.*, 2003; Oehmen *et al.*, 2007). Biological method for removal of phosphate from waste water was first reported by (Levin *et al.*, 1972). Barker and Dold (1996) subsequently identified phosphate removing microorganisms. Fuhs and Chen (1975) studied the morphological feature of the polyphosphate accumulating organisms on the basis of microscopic observations of PAO-enriched sludge. These organisms are non motile, rods or cocci, mostly in the form of clusters having PHB (poly- β -hydroxybutyrate) and Neisser positive granules in the

cells. *Acinetobacter spp.* is considered as the first and main bacterium for the removal of phosphate (Fuhs and Chen, 1975). Under aerobic condition *Acinetobacter lwoffii* is able to remove 75-80% phosphate in the presence of sodium acetate (as a energy source) (Ghigliazza *et al.*, 1998). Uptake of volatile fatty acids is a major feature observed in many microorganisms having enhanced biological phosphorous removal processes (EBPR). However, *Acinetobacter* does not take volatile fatty acids. It indicates that various types of organisms are efficient for EPBR processes. Bacteria like *Proteobacteria*, *Aeromonas*, *Vibrio*, *Pseudomonas* and *Coliform* are efficient for phosphate removal from waste water (Toerien *et al.*, 1990; Kavanaugh, 1991; Snaidr *et al.*, 1997; Seviour *et al.*, 2003). During aerobic phase bacteria take phosphate and accumulate it as poly- P-reserves. Phosphate uptake by bacteria is inhibited in the presence of carbon and phosphate sources at the same time (Smolders *et al.*, 1994a; Kuba *et al.*, 1994). Under such situation carbon source is consumed for the Poly - β - hydroxyalkanoates (PHA) formation. Phosphate uptake occurs after consumption of carbon sources (Mino *et al.*, 1998). In some bacteria, glucose, as a carbon source, enhances the phosphate removal activity (Kim *et al.*, 1998). They have further shown that *Pseudomonas sp.* is able to remove 68.2% phosphate in presence of glucose as a carbon source. During phosphate removal process, the microorganisms produce different types of organic acids and decreasing pH 7.2 to 6.0 of the medium. The phosphate could be reduced below the permissible limit with the help of bacterial consortium (*Bacillus sp.*, *Pseudomonas sp.*, and *Enterobacter sp.*) in the presence of lactose carbon source within seventy-two hours (Krishnaswamy *et al.*, 2009) Mineral salts medium, in the presence of carbon source, enhances the removal of phosphate from phosphate contaminated sediment. In the absence of oxygen bacteria utilize stored polyphosphate as a source of energy for ATP formation with the help of enzyme Poly-p: AMP phosphotransferase (Van-Groenestijn *et al.*, 1989). ATP is used for uptake of volatile fatty acids (VFA) and for its conversion to PHA (Smolders *et al.*, 1994 b). VFA and phosphate transport across the membrane is a energy dependent process and is highly affected by pH. Ratio of VFA and release of phosphate are strongly affected by pH (Smolders *et al.*, 1994 b). Under aerobic condition in the absence of substrate, PHA is used as the substrate. Under such situation bacteria restore the polyphosphate and glycogen and accelerate the phosphate uptake process. In the presence of substrate and electron acceptors, the substrate is converted into PHA (Kuba *et al.*, 1997).

5.3 RECOMMENDATION

The planting of the true mangrove such as the *Rhizophora* species should be encourage than the non-native *Nypa* as it has the ability to recycle and mop-out contaminant from the aquatic environment.

It is recommended that regular monitoring should be put in place to monitor and regulate the concentration of nutrient as the development of social industry and urbanization is currently taking shape at Iko, the pollution of nutrition elements in connection with water quality more and more surface water pollution may arise in the future.

investigating the temporal and spatial distribution of N and P pollution and exposing the correlation between N, P, and water quality parameters is highly recommended which could be used for reference in the surface water pollution control in other industrial cities.

The local, state and federal authority should implement remedial processes (as mentioned above) for easy mitigation/removal of excess nutrient from the mangrove swamp.

Modalities should be put in place to checkmate the dumping of untreated domestic/industrial sewage directly or indirectly into the aquatic ecosystem.

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