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Comparative Study of Sediment Properties between Nypa Fruticans-Dominated and Rhizophora-Dominated Forests in Iko Creek

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript.

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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 stands 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,

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indicating possible change in the sediment profile which may impacts the 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 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.

Keywords: Ecosystem resilience; climate change; sediment properties; microbial interactions.

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 fruticans* thrives due to its specialized adaptations, including underground rhizomes that facilitate vegetative propagation and resist strong water currents (Qureshi & 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 & 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 (Ekpenyong et al., 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., 2012). 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., 2021). 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).

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 (Emoyoma et al., 2020; Sukardjo, 1987).

Therefore, 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.

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

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; and

4. Making recommendations based on the study findings.

2. MATERIALS AND METHODS

2.1 Study Area

This research was carried out in *Rhizophora racemosa* dominated and *Nypa fruiticans* dominated area 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 & Effiong, 2016). (Fig. 1). Iko River is located in the Eastern part of the Niger Delta between 4⁰33′ N – 4⁰50′ N; 7⁰45′ E – 7⁰55′ 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, n.d.). Extensive tidal flats and marshes define the areas adjacent to the 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 & 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 (Ekpe et al., 1995).

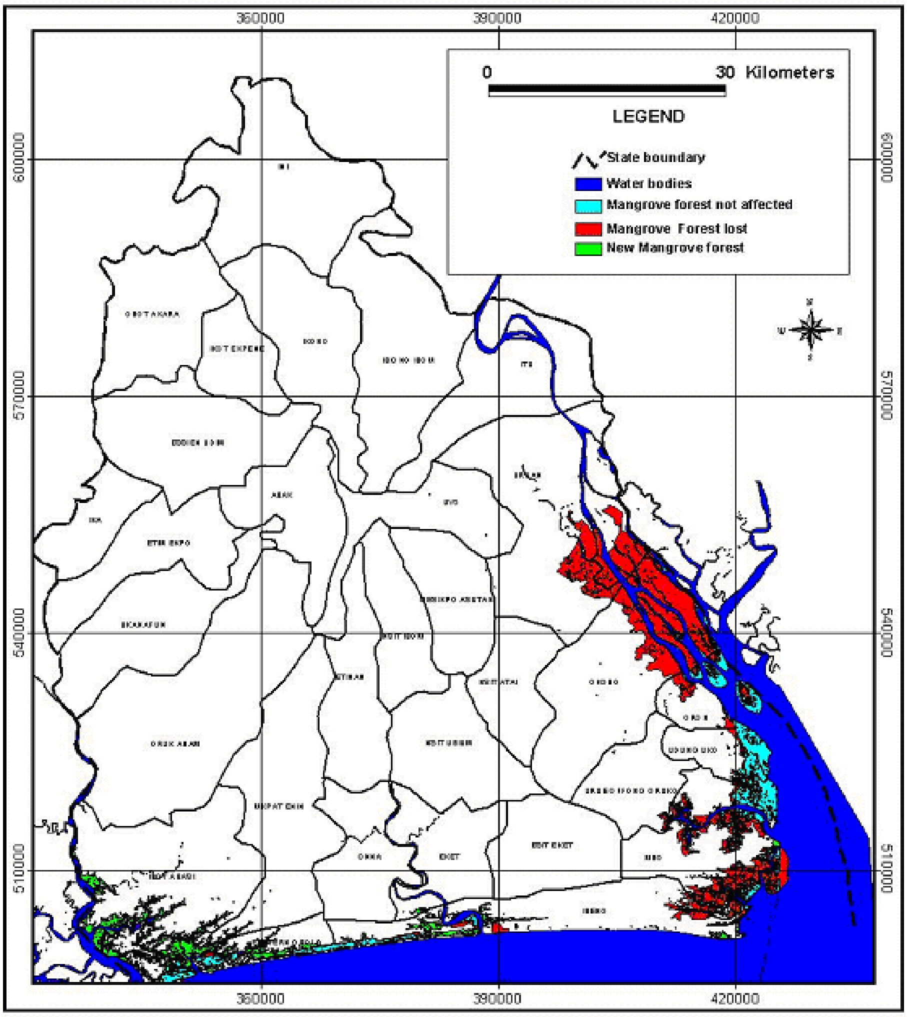

Fig. 1. Map of sampling area

2.1.1 Sample location

Three sampling points along the coast of Iko estuary (three each of the *Nypa fruiticans* and *Rhizophora racemosa* 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.

2.1.2 Sampling

Surface sediment samples at different sampling points was measured at insitu for temperature, dissolved oxygen and salinity while sediment was sub-sampling for laboratory analyses with polyethylene plastic container and labelled immediately at the field. The samples were stored at 4ºC to maintain the present status of the indicated parameters and transported to the laboratory where they were analysed immediately. All analyses were performed following the **American Public Health Association (APHA)** standard procedures (APHA, 2005).

2.2 Physicochemical Analysis

2.2.1 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.

2.2.2 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.

2.2.3 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.

2.3 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 & Koch, 2001). The percentage of organic matter was calculated using the following formula

> % organic matter = (initial weight (g) – final weight (g))/ 100

2.4 Statistical Analysis

Data were analyzed using **SPSS software** (version 22.0). Descriptive statistics summarized water quality parameters, while Comparison of *Rhyzophora racemosa* To *Nypa fruitican* Dominated Sites Using ANOVA. Results were considered significant at $p<0.05$.

3. RESULTS AND DISCUSION

3.1 Physicochemical Parameters

The physico-chemical parameters of sediment taken from three strategic locations at both *Rhizophora racemosa* dominated and *Nypa fruitican* dominated mangrove swamp in Iko, Eastern Obolo L.G.A., as seen in Table 1 and Fig. 2.

3.2 Discussion

The findings highlight distinct ecological differences between *Rhizophora racemosa*- and *Nypa fruticans*-dominated forests. The significant variations in parameters like temperature, pH, DO, and organic carbon emphasize the impact of vegetation type on sediment properties. *Rhizophora* forests appear to support better oxygenation, nutrient cycling, and carbon deposition, contributing to healthier ecosystems.

These results underline the need for targeted conservation strategies, particularly for *Rhizophora racemosa*-dominated habitats, which provide critical ecosystem services. Table 1 compares sediment properties between *Rhizophora racemosa*- and *Nypa fruticans*-dominated forests at Iko Creek using the two-sample t-test. This statistical test evaluates whether the means of the parameters differ significantly between the two sampling sites.

3.2.1 Temperature

The Surface sediment temperature plays an important role for controlling the physicochemical and biological parameters of water and considered as one among the most important factors in the aquatic environment particularly for freshwater (Singh & Mathur, 2005; Akpan et al., 2022). The temperature in surface sediment ranges from 28.0^{O}C to 34.0^{O}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 (Naipal et al., 2013). The lowest temperature of 28.0°C was observed at station 1 in *Rhizophora racemosa* dominated which could be as a result of thick vegetation cover reducing solar radiation with respect to total surface area of the river (Numbere & Camilo, 2017). The analysis shows a significant difference in temperature between *Rhizophora racemosa*-dominated and Nypa-dominated areas (F-statistic: 6.5, P-value: 0.043). The Nypa-dominated areas tend to have higher temperatures than *Rhizophora racemosa*-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 racemosa* 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 racemosa* mangroves were shown to moderate water temperature better than less dense vegetation types (Alongi, 2014). Higher temperatures in Nypa-dominated areas may result from altered canopy structure. *Nypa fruticans* forms less dense canopies compared to Rhizophora racemosa, allowing more sunlight penetration and heating the sediment. Elevated sediment temperatures can affect microbial decomposition rates, nutrient cycling, and species distribution (Nagelkerken et al., 2008).

3.2.2 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 racemosa*-dominated areas tend to have higher DO levels compared to Nypa-dominated areas. The higher DO levels in *Rhizophora racemosa* 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).

3.2.3 Salinity

The significant difference in salinity between *Rhizophora racemosa* and Nypa areas (F-statistic: 9.3, P-value: 0.027) can be attributed to the different tolerances of the vegetation to saltwater. *Rhizophora racemosa* species are well-adapted to high salinity environments and even play a role in moderating salinity by trapping sediments and influencing water exchange (Alongi, 2014). 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 racemosa* species, demonstrate higher salinity tolerance compared to Nypa palms, which are often found further upstream in less saline zones (Nagelkerken et al., 2008).

3.2.4 pH

There is a significant difference in pH levels between the two areas (F-statistic: 15.2, P-value: 0.010). The *Rhizophora racemosa*-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 racemosa* species, produce tannins and other organic acids, which influence the pH of surrounding water (Kathiresan & Bingham, 2001). However, Nypa palms contribute differently to the water chemistry, leading to more acidic conditions. The buffering capacity of *Rhizophora racemosa*-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).

3.2.5 Electrical conductivity (µs/cm)

Electrical conductivity served as a tool to assess the purity of water (Murugesan et al., 2006). The highest electrical conductivity was measure 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 (Rashid & Shrivastava, 2023), 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).

3.2.6 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 supralithorial 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 (Ekpenyong, 2015). Significant differences in organic carbon (F-statistic: 8.1, P-value: 0.025) indicate that *Rhizophora racemosa*-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 racemosa* 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 racemosa*-dominated areas.

3.3 Nutrient Concentration Across Sampling Stations in Iko River Estuary

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 NH_3-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 (Supriyantini et al., 2018). 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., 2017). 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-

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

Parameters Analysed	Rhizophora racemosa Dominated Mean ± SD	Nypa fruitican Dominated Mean ± SD	t-statistic	p-value	Significant Difference
Temperature (°C)	30 ± 4.47	32.33 ± 4.64	2.12	0.043	Yes
pH	7.93 ± 2.30	6.55 ± 2.09	3.89	0.01	Yes
DO (mg/L)	4.07 ± 1.65	2.9 ± 1.39	2.25	0.049	Yes
Salinity (ppt)	28.3 ± 4.35	28.33 ± 4.35	0.02	0.988	No
Phosphate (mg/L)	0.84 ± 0.75	10.33 ± 2.62	-0.29	0.738	No
Nitrate (mg/L)	1.81 ± 1.10	1.23 ± 0.91	2.36	0.032	Yes
Silicate (mg/L)	0.52 ± 0.59	0.84 ± 0.75	0.98	0.33	No
Organic Carbon (mg/L)	2.78 ± 1.36	1.17 ± 0.88	2.45	0.025	Yes
Organic Matter (%)	6.89 ± 2.14	5.89 ± 1.98	1.12	0.29	No
Electrical Conductivity (µS/cm)	1561.93 ± 32.27	1423.88 ± 30.81	1.73	0.08	No

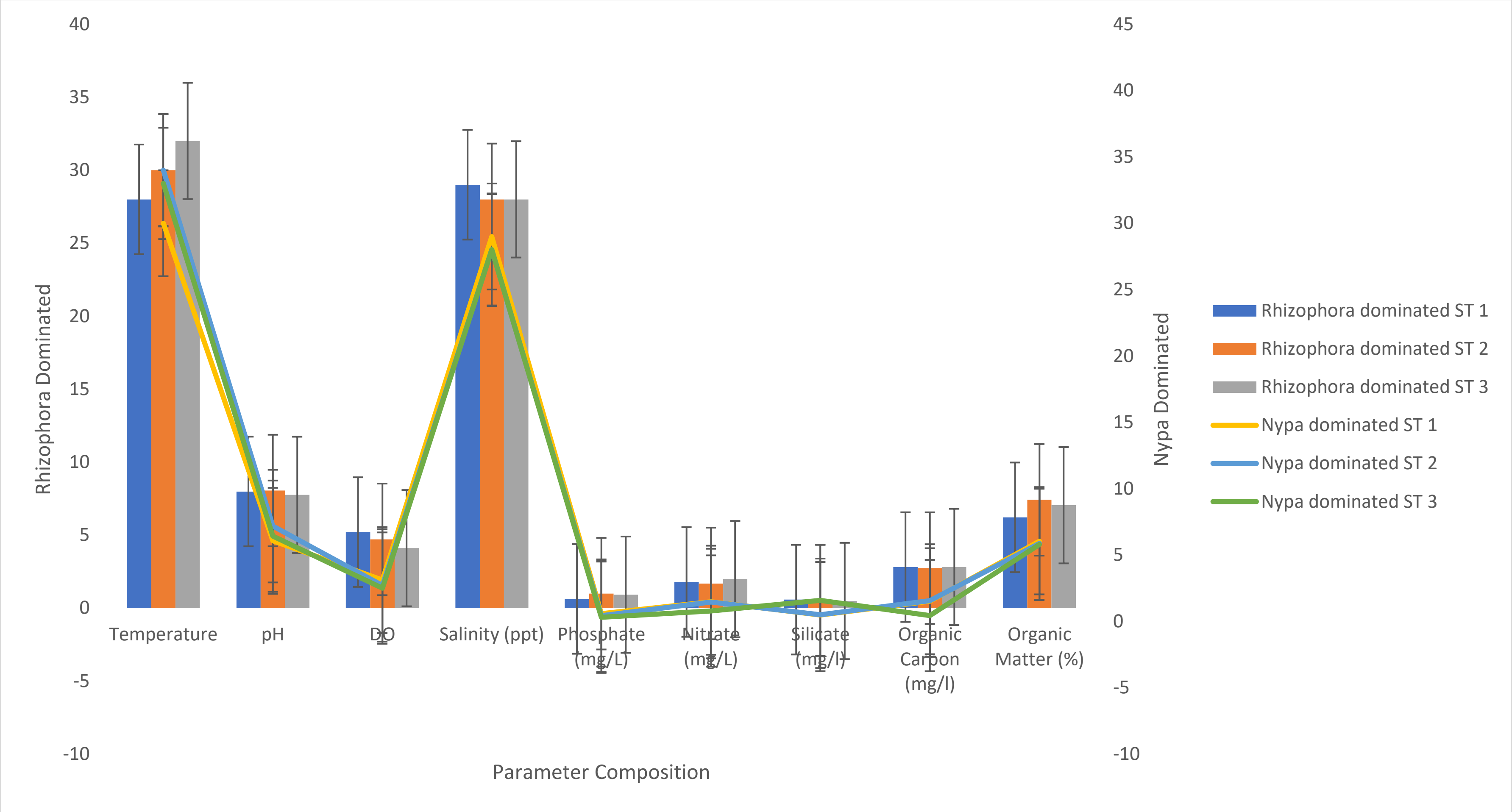

Fig. 2. Physicochemical and nutrient concentration in surface sediment of Rhizophora and Nypa dominated swamp in Iko river estuary

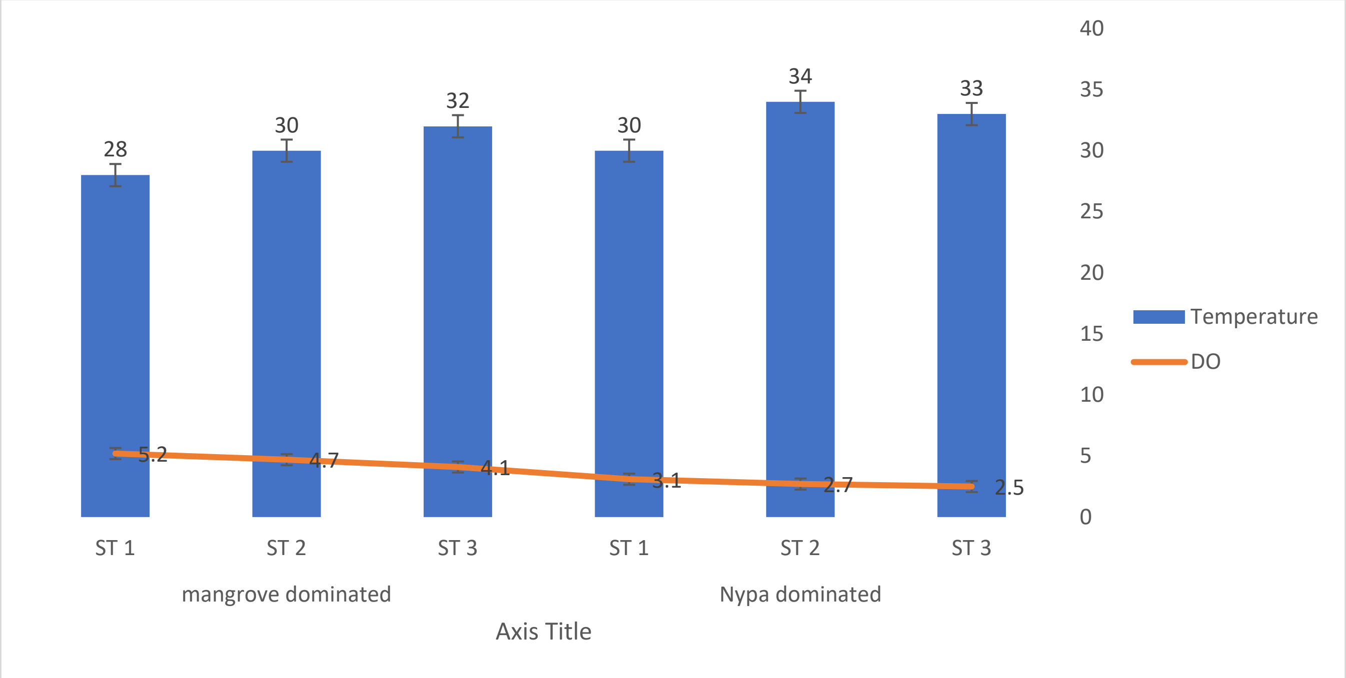

Fig. 3. Temperature and Dissolved Oxygen measurement across Rhizophora and Nypa dominated swamp in Iko river estuary

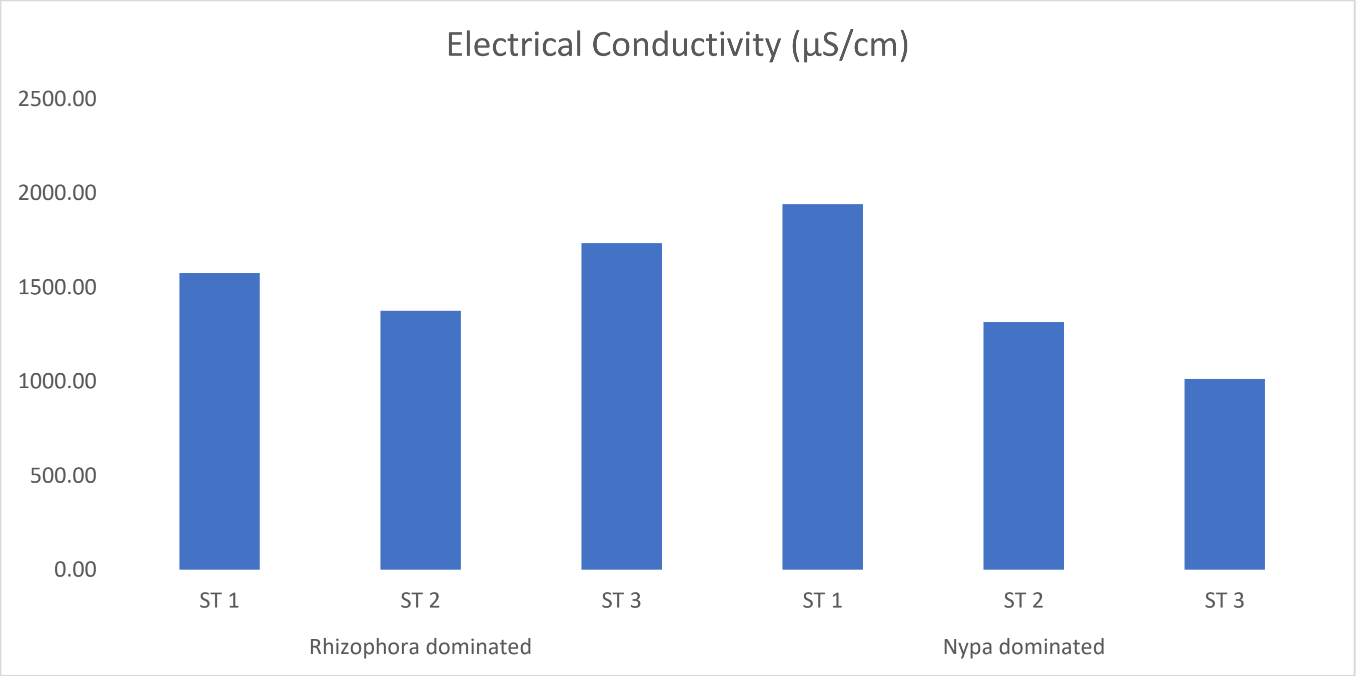

Fig. 4. Electrical conductivity measurement across Rhizophora and Nypa dominated swamp in Iko river estuary

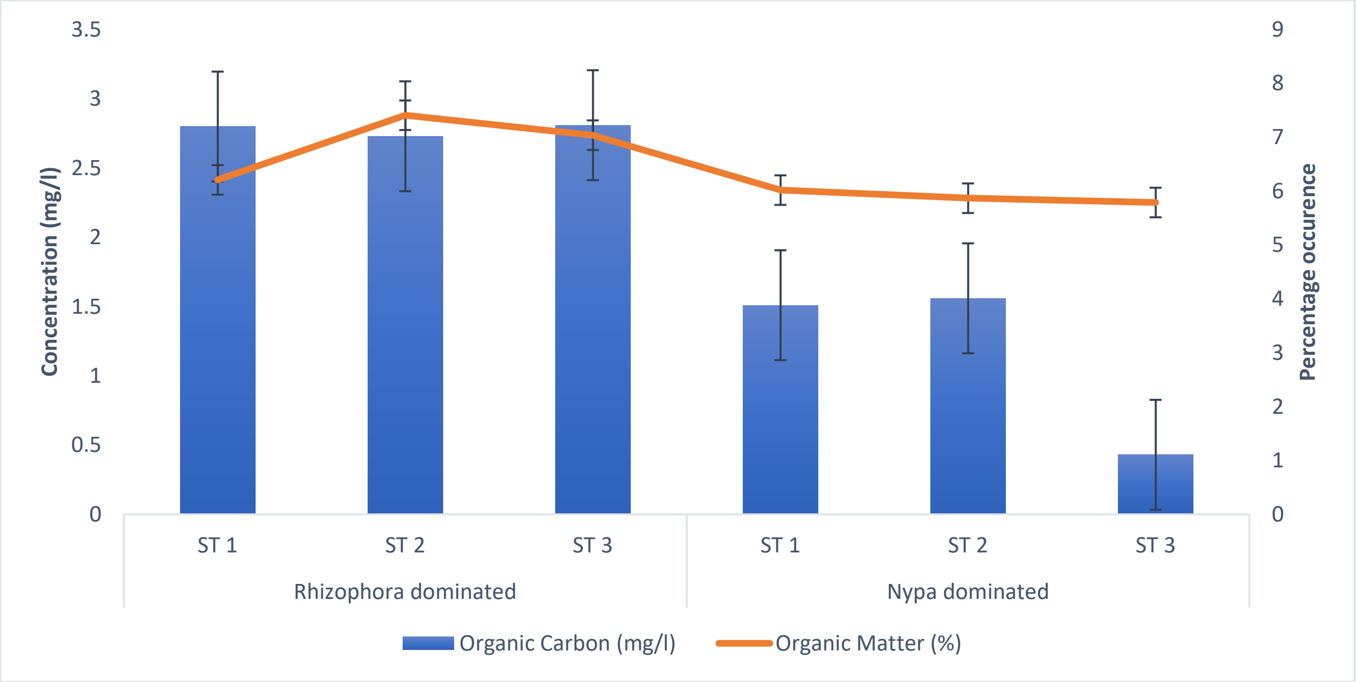

Fig. 5. Organic carbon measurement and percentage occurrence of organic matter across Rhizophora and Nypa dominated swamp in Iko river estuary

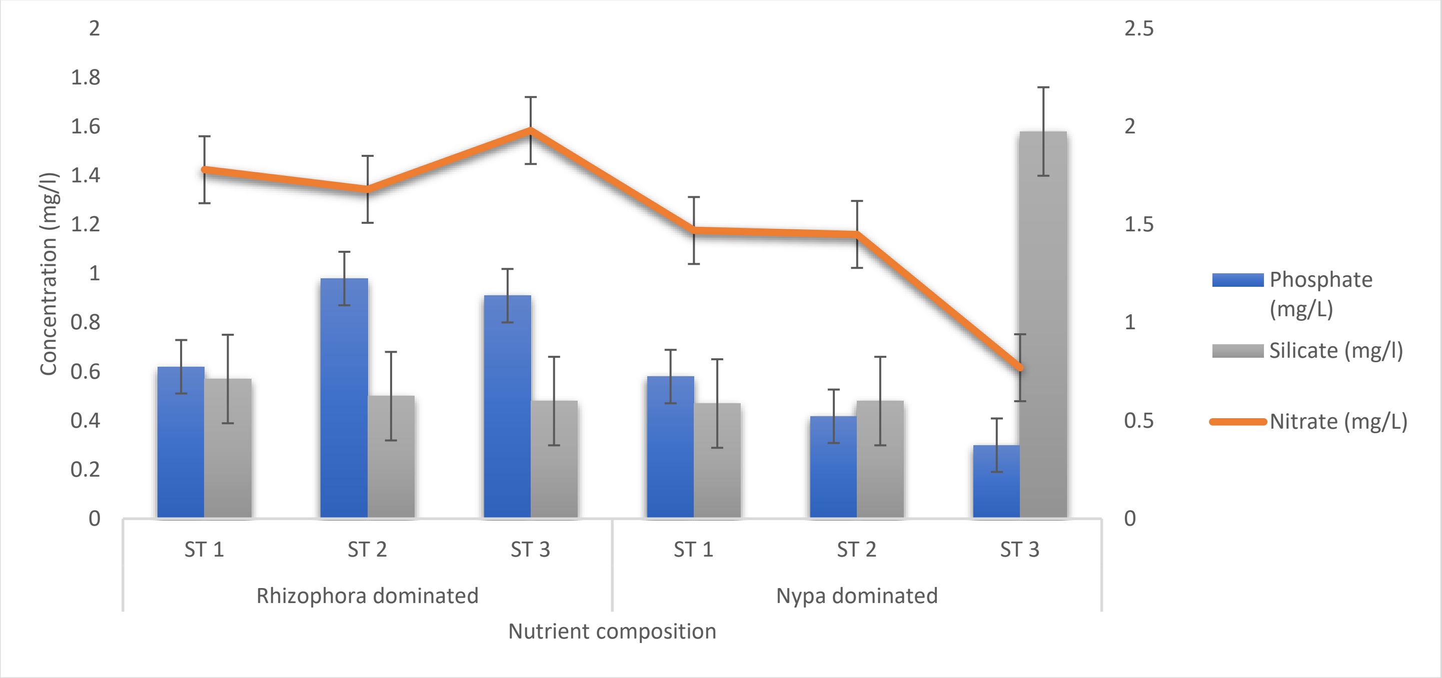

Fig. 6. Nutrient composition across Rhizophora and Nypa dominated swamp

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								
pH	-0.34197	1							
DO	-0.79866	0.830633	1						
Salinity (ppt)	-0.41195	0.478072	0.54452	1					
Phosphate (mg/kg)	-0.43334	0.680266	0.728269	0.626625	1				
Nitrate (mg/kg)	-0.45952	0.70556	0.744037	0.901269	0.799672	1			
Silicate (mg/kg)	0.348906	-0.43688	-0.47833	-0.99426	-0.61227	-0.86458	1		
Organic Carbon (mg/kg)	-0.57831	0.856752	0.900188	0.791225	0.855258	0.949757	-0.74583	1	
Organic Matter (%)	-0.29616	0.703286	0.659564	0.443297	0.964988	0.654184	-0.43824	0.758374	1

statistic: 7.4, P-value: 0.032), with higher concentrations in *Rhizophora racemosa*-dominated areas. This could be due to more efficient nitrogen cycling by mangroves, which act as nitrogen sinks (Alongi, 2014).

3.4 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 of the Rhizophora also, could be washed in by runoff. Similar result was observed by Keuskamp et al., (Keuskamp et al., 2015). Yaakob and others observed that the constant addition of even low levels of nitrogen and phosphorous to an aquatic environment could greatly stimulate algal growth (Yaakob et al., 2021). 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).

3.5 Comparison of Nutrients Across Rhizophora and Nypa Dominated Swamp in Iko River Estuary

Mangroves, such as *Rhizophora racemosa*, are known for their role in nutrient cycling, especially in retaining nitrates, which helps regulate coastal nutrient dynamics (Kathiresan & 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 (Sinha et al., 2017; Keuskamp et al., 2015; Wei et al., 2022; Alongi, 2018; Shi et al., 2022) and this greatly influences the aquatic ecology, especially in estuaries (Wei et al., 2022; Reef et al., 2010; Gohin et al., 2019; Ge et al., 2021; Anand & Arumugam, 2015; Singh et al., 2015). 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 concentrations were positively correlated with organic carbon and organic matter, suggesting a degree of interdependence between these nutrients. Conversely, phosphate and nitrate concentrations negatively correlated with silicate levels (Sukardjo, 1987; Cointet et al., 2019). These relationships, as shown in Table 2, highlight the complex interactions between various nutrients in the mangrove ecosystem.

Additionally, statistical analysis revealed significant differences ($p < 0.05$) among the measured parameters, emphasizing the dynamic nutrient cycling occurring in these habitats.

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 & 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.

3.6 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 CO_2 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 & 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 (Blanar 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 & 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.

4. 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.

Heavy nutrient load (nitrate and phosphate) containing surface sediment 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 asthetic 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.

The investigation of Rhizophora and Nypa dominated sediment properties reveal 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 microbs 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 racemosa 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.

4.1 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 accepter in the absence of oxygen. This process is known as nitrate respiration or dissimilatory nitrate reduction (Focht & 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 & 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 & Højberg, 1999; Brunet & Garcia-Gil, 1996; Otte et al., 1999). Thioploca has a capacity to reserve sulfur and nitrate in vacuoles (Schulz & Jørgensen, 2001). It takes nitrate and uses it to oxidize sulfur in sulfide rich anoxic porewater (Yuan et al., 2012).

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

Bacteria accumulate phosphate from phosphate-contaminated wastewater inside their cells in polyphosphate granules, a process well-documented in enhanced biological phosphorus removal (EBPR) systems (Nielsen et al., 2019; Levin et al., 1972). The biological removal of phosphate from wastewater was first reported in the 1970s (Yuan et al., 2012), and subsequent studies identified specific phosphate-removing microorganisms (Nielsen et al., 2019; Seviour & Mino, 2003). The morphological characteristics of polyphosphate-accumulating organisms (PAOs) were first observed microscopically in PAO-enriched sludge, revealing non-motile rod- or cocci-shaped bacteria clustered with poly-β-hydroxybutyrate (PHB) and Neisser-positive granules (Nielsen et al., 2010).

Among PAOs, *Acinetobacter* spp. was initially considered the primary bacterium responsible for phosphate removal (Fuhs & Chen, 1975). Under aerobic conditions, *Acinetobacter lwoffii* can remove 75–80% of phosphate using sodium acetate as an energy source (He & McMahon, 2011). However, modern studies suggest that *Acinetobacter* plays a less prominent role in EBPR processes than initially thought. Instead, other bacterial groups, such as *Candidatus Accumulibacter phosphatis* and *Tetrasphaera*, are now recognized as dominant PAOs in EBPR systems (Nielsen et al., 2019; Oehmen et al., 2007). Uptake of volatile fatty acids (VFAs) is a key feature of many PAOs, although *Acinetobacter* does not utilize VFAs, indicating the presence of diverse microorganisms in EBPR systems capable of efficient phosphate removal (Yuan et al., 2012; Seviour & Mino, 2003).

Several bacterial genera, including *Proteobacteria*, *Aeromonas*, *Vibrio*, *Pseudomonas*, and *Coliform*, have been identified as efficient for these bacteria uptake phosphate and store it as polyphosphate reserves. However, phosphate uptake is inhibited when both carbon and phosphate sources are present simultaneously, as the carbon source is used for poly-β-hydroxyalkanoates (PHA) formation (Smolders et al., 1994; Kuba et al., 1997). Phosphate uptake typically resumes after carbon source consumption (Mino et al., 1998). Glucose as a carbon source has been shown to enhance phosphate removal activity in some bacteria, such as *Pseudomonas* spp., which can remove up to 68.2% of phosphate in its presence (Kim et al., 1998).

During the phosphate removal process, microorganisms produce organic acids that lower the pH of the medium from 7.2 to 6.0. A consortium of *Bacillus* spp., *Pseudomonas* spp., and *Enterobacter* spp. has demonstrated the ability to reduce phosphate concentrations to below permissible limits in 72 hours using lactose as a carbon source (Krishnaswamy et al., 2009). Mineral salt media with carbon sources further enhance phosphate removal efficiency. Under anaerobic conditions, bacteria utilize stored polyphosphate as an energy source for ATP production, facilitated by the enzyme poly-P: AMP phosphotransferase (Van Groenestijn et al., 1989). ATP is used for VFA uptake and conversion to PHA, which is energy-dependent and influenced by pH (Smolders et al., 1994). In the aerobic phase, bacteria restore polyphosphate and glycogen reserves, accelerating phosphate uptake in the absence of substrates (Kuba et al., 1997).

5. 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.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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