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Restoration and treatment of surface water affected by mining wastewater: Environmental consequences and control methods in South-South Nigeria

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Abstract
Heavy metals, particularly mercury (Hg), are highly toxic to both the environment and human health. Exposure to heavy metals has been associated with several adverse health effects, including neurological disorders, kidney damage, and respiratory complications. In this study, the search for novel and cost-effective adsorbents for reducing mercury concentrations in water samples collected from River Niger in the southern region of Nigeria was investigated. The turbidity analysis of water samples obtained from Edo, Rivers, and Akwa Ibom States revealed that the river water was highly turbid, with an average turbidity value of 355 NTU, making it unsuitable for domestic use without adequate treatment. A series of batch adsorption experiments were carried out using unmodified rice husk (UM-RH) and unmodified orange peel (UM-OP) as adsorbents for mercury removal. The results showed that the adsorption process was influenced by parameters such as pH, contact time, and adsorbent dosage. Optimum adsorption conditions were achieved at pH 5 using 0.5 g/20 ml of adsorbent at 35°C ± 2 over four hours. Under these conditions, UM-RH recorded the highest adsorption efficiency of 45.11%, while UM-OP showed a lower efficiency of 42.39% for mercury removal. Furthermore, the Langmuir isotherm model provided a better fit for the experimental data than the Freundlich isotherm model.

Keywords: Remediation, surface water, pollution, mining, discharges South-South, Nigeria

Introduction

Surface water is one of the most valuable natural resources for human survival, economic development, and ecological sustainability (Akacha *et al*., 2025)[2]. Rivers, streams, wetlands, estuaries, and lakes provide water for domestic consumption, agriculture, fisheries, transportation, industrial production, and recreation. In developing countries such as Nigeria, surface water resources play a particularly critical role because a large proportion of rural and peri-urban populations depend directly on natural water bodies for drinking, cooking, irrigation, and livelihood activities (Ikechukwu *et al*., 2026) [8]. However, rapid industrialization, urban expansion, population growth, and increased exploitation of natural resources have significantly contributed to the degradation of surface water quality across many regions of the world. One of the major causes of this degradation is the discharge of untreated or poorly treated industrial and mining effluents into nearby rivers and streams (Obruche *et al*., 2018) [18]. Mining activities are globally recognized as major contributors to environmental pollution due to the release of contaminants such as suspended solids, heavy metals, hydrocarbons, acids, and toxic chemicals into surrounding ecosystems. Mining operations, including quarrying, sand mining, dredging, crude oil exploration, and mineral extraction, generate large volumes of waste materials that can enter water bodies through runoff, seepage, erosion, and direct effluent discharge (Jacintha *et al*., 2025) [10]. These pollutants alter the physicochemical and biological characteristics of surface water, thereby reducing water quality and threatening aquatic ecosystems and public health. In many developing nations, weak environmental regulations, poor enforcement of waste management policies, and inadequate remediation practices have exacerbated the pollution problem associated with mining operations (Kehinde *et al*., 2025) [11]. Surface water pollution from mining activities has become a major environmental concern because contaminated water can accumulate toxic substances that persist in the environment for long periods. Heavy metals such as lead, cadmium, chromium, nickel, manganese, and iron are common pollutants associated with mining and industrial activities. These contaminants are non-biodegradable and may bioaccumulate within aquatic organisms, eventually entering the food chain and posing severe risks to human health. Polluted water bodies may also experience reduced dissolved oxygen levels, increased turbidity, acidification, and destruction of aquatic habitats (Micheal *et al*.,2026) [12]. Consequently, communities that rely on these water resources often suffer from waterborne diseases, reduced agricultural productivity, declining fish populations, and socioeconomic hardship. Globally, increasing awareness of environmental sustainability has led to growing interest in the remediation of polluted surface waters (Etus & Obruche, 2026) [5]. Remediation refers to the processes, technologies, and management strategies used to remove, neutralize, or reduce contaminants in polluted environments in order to restore ecological balance and improve water quality. Various remediation approaches have been developed and applied worldwide, including physical, chemical, biological, and integrated treatment methods (Micheal *et al*.,2026). Physical remediation techniques involve sediment removal, filtration, aeration, and containment systems, while chemical methods involve precipitation, adsorption, oxidation, and coagulation processes. Biological remediation, also known as bioremediation, utilizes microorganisms, algae, fungi, and aquatic plants to degrade or absorb pollutants from contaminated water bodies. In recent years, sustainable and eco-friendly remediation technologies such as phytoremediation, constructed wetlands, and nanotechnology-based treatment systems have gained attention due to their cost-effectiveness and

environmental compatibility. In Nigeria, environmental pollution associated with extractive industries has become increasingly severe, particularly in the oil-producing and mineral-rich regions (Moses *et al*., 2025) [14]. The South-South region of the country, which includes states such as Edo State, Rivers State, and Akwa Ibom State, is endowed with abundant natural resources including crude oil, limestone, sand, gravel, and other mineral deposits. These resources have contributed significantly to the economic growth of the nation through mining, quarrying, dredging, and petroleum exploration activities (Nathan *et al*., 2025) [15]. Despite the economic importance of these industries, their operations have generated serious environmental challenges, especially the contamination of surface water systems. In Edo State, quarrying and limestone mining activities in areas such as Ikpeshi and other parts of Akoko-Edo have been linked to surface and groundwater pollution. Studies conducted in these mining communities revealed elevated levels of heavy metals and physicochemical pollutants in nearby rivers and quarry pits, indicating the influence of mining wastes on water quality (Obruche *et al*., 2019) [17]. The discharge of untreated mining effluents, erosion of exposed land surfaces, and accumulation of sediments contribute significantly to water contamination in the region. Similarly, Port Harcourt, one of the major industrial and oil-producing cities in the Niger Delta region, has experienced extensive environmental degradation resulting from petroleum exploration, refining activities, dredging, industrial discharges, and urban waste disposal. Rivers and estuaries within the city and surrounding communities have been subjected to pollution from hydrocarbons, trace metals, and other industrial contaminants (Erienu *et al*., 2022) [4]. Research on the Bonny/New Calabar River Estuary and other water bodies in the area revealed high concentrations of heavy metals and deteriorating water quality linked to industrial and oil-related activities. In Akwa Ibom State, surface water pollution has also become a significant concern due to crude oil production, gas flaring, sand mining, dredging, and industrial activities along riverine and coastal communities. Water bodies such as the Qua Iboe River and Iko River have shown evidence of contamination from hydrocarbons and heavy metals associated with oil exploration and mining activities. Several studies reported increased levels of pollutants in surface water and sediments near oil facilities and mining locations, indicating serious ecological risks to aquatic ecosystems and local populations (Odimgbe *et al*., 2026) [20]. The continuous discharge of mining effluents into rivers and streams in these regions has resulted in declining water quality, destruction of aquatic habitats, and threats to public health. Many local communities depend directly on these water bodies for fishing, farming, domestic use, and transportation, thereby increasing their vulnerability to pollution-related hazards. Inadequate wastewater treatment systems, weak enforcement of environmental regulations, and limited adoption of sustainable remediation practices have further intensified the problem (Ogwuche and Obruche, 2020) [21]. Consequently, there is an urgent need for effective remediation strategies that can restore polluted surface water systems and ensure sustainable environmental management in the South-South region of Nigeria. Therefore, this study focuses on the remediation of surface water polluted by effluent discharges from mining activities in the South-South region of Nigeria, with specific emphasis on Edo State, Port Harcourt, and Akwa Ibom State. The study seeks to examine the nature and extent of surface water contamination resulting from mining and industrial effluents, evaluate the environmental and health implications of such pollution, and explores appropriate remediation approaches for improving water quality and protecting aquatic ecosystems (Itodo *et al*., 2021) [9]. By addressing these challenges, the study aims to contribute to sustainable water resource management, environmental protection, and public health improvement in the Niger Delta and surrounding regions of Nigeria.

Materials and Method

Experimental setup

This research was divided into two main sections. The first section focuses on evaluating the physicochemical properties of water samples obtained from the River Niger at Edo, Akwa Ibom, and Port Harcourt, comparing these properties to the WHO standards for safe drinking water. The second section emphasizes the reduction of Mercury (Hg) levels in the water samples by employing agricultural waste as an adsorbent, as well as identifying the optimal conditions for this adsorption process through batch testing (Okpanachi *et al*., 2025) [22].

Collection of Samples

The sampling and preservation procedures followed the methodologies outlined by Obruche *et al*. (2019) [19] and Sarah *et al*., (2026) [24]. Water samples were collected from the River Niger at Edo, Akwa Ibom, and Port Harcourt, situated in the South South region of Nigeria. The sampling sites were chosen near areas where small-scale mining activities take place, and the wastewater generated by these miners is released into the river. The samples were collected in airtight polypropylene bottles that had been thoroughly cleaned and rinsed with distilled water. For the analysis of heavy metals, the samples were acidified with nitric acid immediately upon collection to reduce the pH to below 2. This step is crucial as maintaining a pH below 2 helps to prevent precipitation and adsorption to the walls of the container. Any acid could be used to oxidize the samples; however, HNO_3 is preferred due to its strong oxidizing capabilities. The addition of HNO_3 to the samples converts the metal ions into their nitrate salts, which are highly soluble. Another important reason for choosing HNO_3 over other acids is that sample digestion is required prior to Atomic Adsorption Spectroscopic analysis, as this process aims to eliminate any matrix that could potentially interfere during atomization. Digestion also guarantees that all types of the metal are transformed into a uniform oxidation state. The leftover samples designated for physicochemical analysis were preserved at temperatures between 1 °C and 4 °C.

Adsorbent Collection and Pre-Preparation

Rice husks were obtained from a rice mill located in Benue State, Nigeria. Orange peels were gathered from farms within the Unenurhie community in Delta State. Water samples were taken from the branches of the Niger River situated in the South South region of Nigeria.

Preparation of Unmodified Rice Husk and Unmodified Orange Peel Adsorbents

This preparation was executed in accordance with Ugochukwu (2025) [25] and Umudi *et al*. (2026) [26]. The rice

husk underwent thorough washing with distilled water. Following the cleaning process, the rice husks were dried in an oven at a temperature of 50°C for a period of 12 hours. Subsequently, they were crushed using a mortar and pestle and sieved to obtain a particle size of 1 mm. The sieved particles were stored in a clean, airtight polypropylene bottle labeled UM-RH (Unmodified Rice Husk). The same methodology was applied to the orange peels, and the resultant product was placed in a clean airtight polypropylene bottle labeled UM-OP (Unmodified Orange Peel).

Standard Preparation

A standard solution of mercury (Hg) was prepared from the 1000 mg/L reference solutions of Hg. The standards were diluted to concentrations ranging from 0.1 mg/L to 2.5 mg/L and were stored in polypropylene bottles.

Digestion Process

The digestion process was conducted following the procedures outlined by Obruche *et al*. (2019) and Umudi *et al*. (2025). Approximately 50 ml of the water sample from the Niger River was transferred into a round-bottom flask, to which 5 ml of concentrated HNO_3 (69%) was added. The mixture was heated and evaporated on a hot plate until the volume was minimized to the lowest feasible level (approximately 10 ml). After digestion, the flask was rinsed with distilled water, and the mixture was filtered through Whatman filter paper with a pore size of 0.45 µm. A volume of 5 ml of the filtrate was transferred into a 10 ml volumetric flask and diluted to the mark with distilled water. A portion of this solution was subsequently analyzed for lead and mercury using the Atomic Absorption Spectrophotometer (AAS).

Batch Test

Variation of pH

The previously mentioned procedure was applied to UM-RH, with modifications to the method described by Abeokuta *et al*. (2025) [1]. Precisely 0.1 g of the UM-RH was added to 20 ml of the water sample and mixed thoroughly to create a homogenous mixture. A similar homogenous mixture of 0.1 g of unmodified orange peel was also prepared. The pH of each mixture was adjusted to 5 using 0.1M HCl or 0.1 M NaOH solutions. Both mixtures were placed on the same shaker at a speed of 175 rpm in an oven maintained at 35 °C ± 2 for a duration of 4 hours. The mixtures were then filtered using 0.45µm Whatman filter paper. Following this, 10 mL of each solution was digested (as previously described), and the resulting filtrate was analyzed using AAS. This process was repeated for pH levels of 6, 7, 8, and 9.

Variation of Adsorbent Dosage

Exactly 0.1 g of the UM-RH was added to 20 ml of the water sample and mixed thoroughly to achieve a homogenous mixture. A comparable homogenous mixture of 0.1 g of unmodified orange peel was also prepared. Each mixture was adjusted to an optimal pH of 5; both mixtures were then placed on the same shaker at a speed of 175 rpm in an oven maintained at 35 °C ± 2 for a duration of 4 hours. After this, 10 ml of each solution was digested (as previously described), and the filtrates were analyzed using AAS. This process was repeated for dosages of 0.2 g, 0.3 g, 0.4 g, and 0.5 g.

Variation of Contact Time

Exactly 0.1 g of the UM-RH was added to 20 ml of the water sample and mixed thoroughly to achieve a homogenous mixture. A comparable homogenous mixture of 0.1 g of unmodified orange peel was also prepared.

Each mixture was adjusted to an optimal pH of 5; subsequently, both mixtures were placed on the same shaker operating at a speed of 175 rpm within an oven maintained at 35 °C ± 2 for a duration of 4 hours. Following this, 10 ml of each solution underwent digestion (as previously described), and the filtrate was analyzed using Atomic Absorption Spectroscopy (AAS). This procedure was repeated for contact durations of 1, 2, 3, and 5 hours (Obruche *et al*., 2025) [16].

Analysis

An Atomic Absorption Spectrophotometer (AAS), specifically the Perkin-Elmer Pin Accle 900T model, was employed at the Ecological Laboratory of the University of Nigeria to determine the concentrations of mercury (Hg) in water samples collected from the River Niger during each variation process, measured at wavelengths of 283.3 nm and 253.7 nm, respectively. The analysis of metal concentrations was performed using an air-acetylene flame for lead and the hydride generation/cold vapour technique for mercury, utilizing their respective hollow cathode tubes. The concentrations of Hg were established in relation to the corresponding standard solutions. The initial concentrations of Hg in the River Niger were recorded as 0.266 ppm and 0.185 ppm, respectively.

Adsorption Isotherm

The water samples from the River Niger were spiked to achieve varying concentrations of Hg, ranging from 0.5 mg/L to 2.5 mg/L. The adsorption capacities of rice husk, orange peel, and their modified forms were assessed using the Langmuir and Freundlich adsorption isotherms. The adsorption process was conducted at a pH of 5, with a contact time of 4 hours and an adsorbent dosage of 0.5 g per 20 ml at a temperature of 35 °C ± 2. The quantity of Hg adsorbed was calculated using the following equation:

$$qe = \frac{(CO - Ce)v}{m}$$

Where;

qe represents the adsorbent concentration once equilibrium has been reached.

V denotes the total volume of the solute solution (in liters)

Co indicates the initial concentration of the solute (in mg/L).

Ce (in mg/L) is residual equilibrium concentration of the solute post-adsorption

m signifies the mass of the adsorbents utilized (in grams).

Calculations were performed for both the Langmuir Adsorption Isotherm and the Freundlich adsorption Isotherm.

Statistical Analysis

The data obtained from the laboratory experiment underwent analysis of variance (ANOVA). Comparisons were made among the data from different groups, with differences considered significant at $p<0.05$. The analysis was conducted using SPSS software version 18.

Results and Discussion

Table 1 show the results of the physicochemical parameters from the three sampling sites compared with the W.H.O Guidelines for Potable Water.

Table 1: Physicochemical parameters of River Niger at Edo, Port Harcourt and Akwa Ibom

River Niger sources in various states				
Parameter	**Delta**	**Bayelsa**	**CRS**	**W.H.O**
Turbidity (NTU)	356	360	350	5
Colour (apparent) (Hz)	150	161	159	15
pH	7.31	7.5	7.61	6.5 - 8.5
Conductivity (µS/cm)	108	115	110	1500
Total Suspended Solids (mg/L)	1	1.2	1.08	-
Total Dissolved Solids(mg/L)	59.4	60.9	61	1000
Sodium (mg/L)	3.1	3.3	3.5	200
Potassium (mg/L)	1.2	1.08	1.3	30
Calcium (mg/L)	7.46	7.35	7.6	200
Magnesium (mg/L)	6.65	7.01	7.02	150
Total Iron (mg/L)	0.581	0.591	0.6	0.3
Ammonia (NH4-N) (mg/L)	0.11	0.114	0.109	0.00 – 1.5
Chloride (mg/L)	9.93	10.01	9.89	250
Sulphate(SO4) (mg/L)	11.5	10.9	11.35	250
Phosphate (PO4-P) (mg/L)	0.054	0.049	0.072	-
Manganese (mg/L)	0.496	0.501	0.508	0.4
Nitrite (NO2-N) (mg/L)	0.013	0.013	0.012	1.0
Nitrate (NO3-N) (mg/L)	0.116	0.115	0.113	10
Total Hardness (as CaCO3)(mg/L)	46	44	48	500
Total Alkalinity (as CaCO3) (mg/L)	26.4	26.5	27	-
Calcium CaCO3) (mg/L) Hardness (as	18.6	18.6	18.9	-
Magnesium (as CaCO3) (mg/L)	27.4	28	27.7	-
Fluoride (mg/L)	0.156	0.154	0.156	1.5
Bicarbonate (mg/L)	32.2	32.2	32.2	-
Carbonate (mg/L)	0	0	0	-

The physicochemical characteristics of the River Niger water samples collected from Delta, Bayelsa, and Cross River States are presented in Table 1 and compared with the World Health Organization (WHO) standards for potable water. The results revealed that most of the measured parameters were within the acceptable WHO limits, indicating that the river water possesses relatively good chemical quality. However, some important parameters such as turbidity, colour, iron, and manganese exceeded the recommended limits, suggesting contamination and the need for treatment before domestic use. The turbidity values recorded for Delta, Bayelsa, and Cross River States were 356 NTU, 360 NTU, and 350 NTU respectively, which were significantly higher than the WHO permissible limit of 5 NTU. High turbidity indicates the presence of suspended particles such as clay, silt, organic matter, and other impurities in the water. Excessive turbidity reduces water clarity and may provide a medium for microbial growth. The elevated turbidity observed in this study may be attributed to unregulated mining activities, erosion, dredging, and runoff into the river system. Similar observations had been reported in related studies where mining activities increased sediment load in surface waters. Closely related to turbidity was the colour of the water, which ranged from 150–161 Hz and exceeded the WHO limit of 15 Hz. The high colour values may result from dissolved organic substances and corrosion of metallic materials such as iron and copper. The pH values obtained ranged from 7.31 to 7.61, which fall within the WHO recommended range of 6.5–8.5. This indicates that the river water is slightly alkaline and suitable for most biological and chemical processes. Conductivity values ranged from 108–115 µS/cm, which were far below the WHO limit of 1500 µS/cm, indicating low ionic concentration and low salinity. Total dissolved solids (TDS) values of 59.4–61 mg/L were also within the acceptable limit of 1000 mg/L, showing that the water contains low levels of dissolved inorganic substances. Similarly, total suspended solids (TSS) values were relatively low, indicating moderate particulate contamination. The concentrations of sodium, potassium, calcium, and magnesium were all below WHO permissible limits. Sodium concentrations ranged from 3.1–3.5 mg/L, while potassium ranged from 1.08–1.3 mg/L. Calcium and magnesium concentrations were also low, indicating that the river water is moderately soft. This was confirmed by the total hardness values of 44–48 mg/L, which were far below the WHO limit of 500 mg/L. Soft water is advantageous for domestic use because it reduces soap consumption and scaling in pipes.

Iron concentrations ranged from 0.581–0.600 mg/L, exceeding the WHO limit of 0.3 mg/L. Elevated iron concentrations in water may arise from geological formations, industrial discharges, and corrosion of metallic materials. Excess iron in water may impart unpleasant taste, staining of laundry and plumbing fixtures, and may affect aquatic organisms. Similarly, manganese concentrations ranged from 0.496–0.508 mg/L, exceeding the WHO permissible limit of 0.4 mg/L. High manganese concentrations may affect water quality and pose health concerns when consumed over prolonged periods.

Other parameters such as ammonia, chloride, sulphate, nitrite, nitrate, fluoride, alkalinity, bicarbonate, and phosphate were all within acceptable limits, suggesting minimal nutrient pollution and low risk of eutrophication.

The low nitrate and nitrite concentrations indicate limited contamination from agricultural runoff or sewage discharge (Etus & Obruche, 2026) [6].

Results from Batch Test

The batch adsorption experiments further demonstrated the potential of unmodified rice husk (UM-RH) and unmodified orange peel (UM-OP) as adsorbents for mercury (Hg) removal from contaminated water.

Effect of pH

The effect of pH showed that maximum adsorption occurred at pH 5 for both adsorbents. This suggests that acidic conditions favour mercury adsorption due to increased attraction between positively charged mercury ions and negatively charged functional groups on the adsorbent surfaces. As pH increased, adsorption efficiency decreased due to electrostatic repulsion between negatively charged adsorbent surfaces and mercury ions. A similar work conducted by Obruche *et al*., 2018 showed a higher adsorption of Hg at pH 5.3.

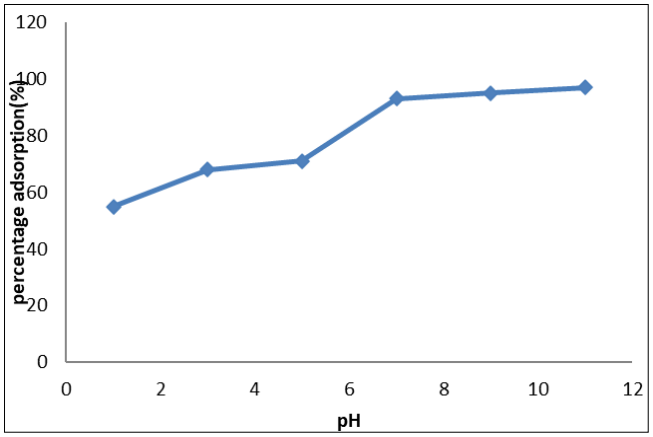

Fig 1: Effect of pH on UM-RH and UM-OP

Effect of Contact time

The effect of contact time revealed that adsorption efficiency increased with increasing contact time, with optimum adsorption occurring at 4 hours. This indicates that sufficient time is required for mercury ions to diffuse and occupy available adsorption sites until equilibrium is reached. A similar work carried out by Obruche *et al*., (2019) [19] confirmed the observed trend.

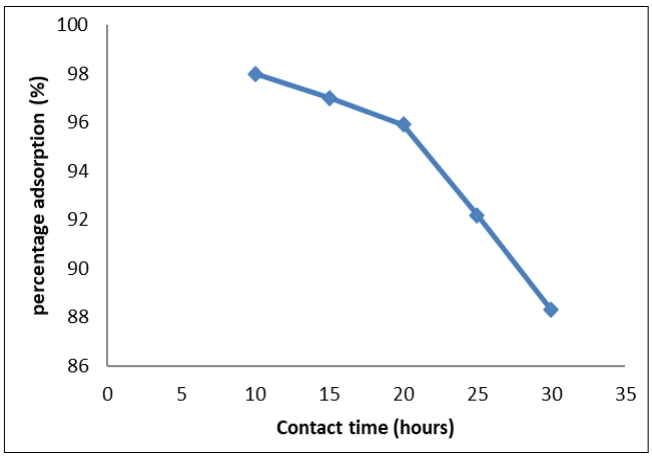

Fig 2: Effect of contact time on UM-RH, and UM-OP

Effect of adsorbent dosage

The effect of adsorbent dosage also showed that adsorption efficiency increased with increasing dosage, with optimum performance observed at 0.5 g. Higher dosage increases surface area and availability of active adsorption sites. Ekpo *et al*.,(2023) [3] reported similar work.

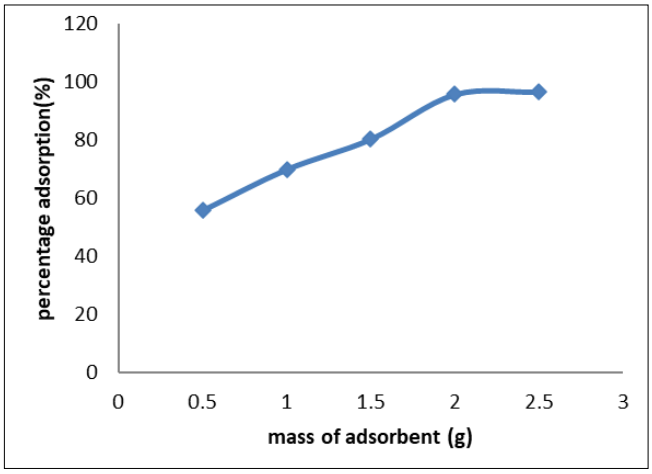

Fig 3: Effect of dosage on UM-RH and UM-OP

Adsorption Isotherms

Langmuir Adsorption Isotherm for UM-RH

Figures 4 show Langmuir adsorption isotherms for Hg

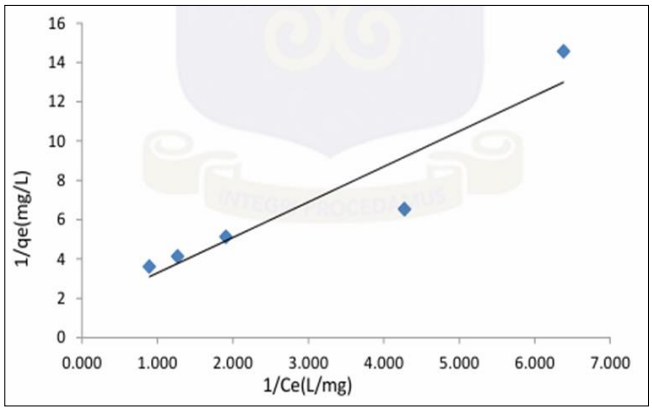

Fig 4: Langmuir isotherm for Hg adsorption using UM-RH

Langmuir Adsorption Isotherm for UM-OP

Figures 5 show Langmuir adsorption isotherms for UM-OP for Hg,

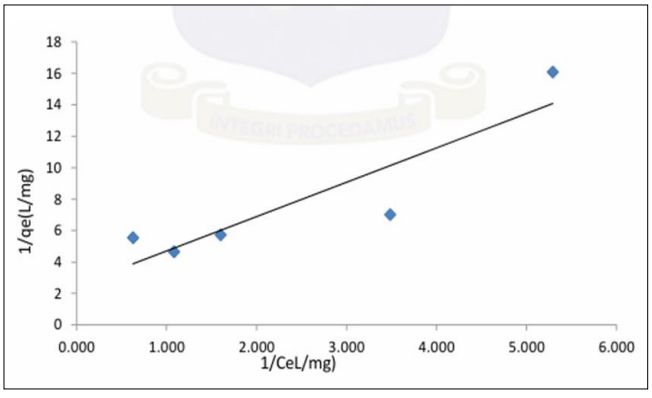

Fig 5: Langmuir isotherm for Hg adsorption using UM-OP

Table 2: Langmuir isotherm parameters for Hg for UM-RH and UM-OP

Treatment Intercept	Slope	qm	Ka	R2
UM-RH 1.4847	1.8025	0.67353674	0.82368932	0.8755
UM-OP 2.5177	2.1853	0.39718791	1.15210726	0.8123

Freundlich Isotherms

Freundlich Adsorption Isotherm for UM-RH

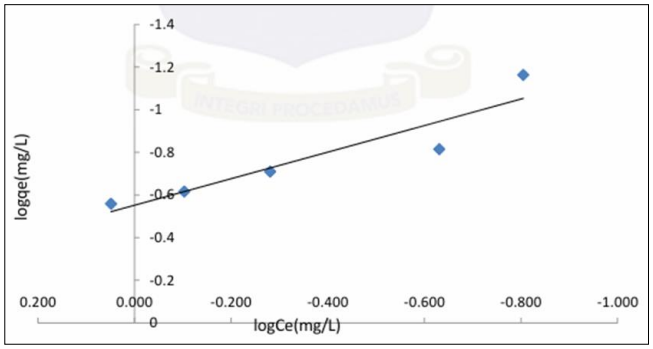

Fig 6: Freundlich isotherm for Hg adsorption using UM-RH

Freundlich Adsorption Isotherm for UM-OP

Figures 7 show Freundlich adsorption isotherms for UM-OP for Hg.

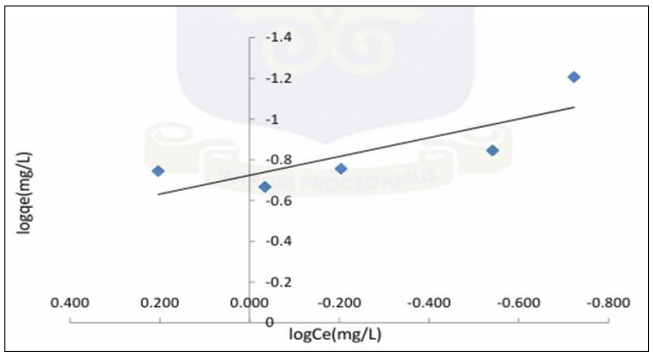

Fig 7: Freundlich isotherm for Hg adsorption using UM-OP

Table 3: Freundlich isotherm parameters for Hg for UM-RH and UM-OP

Intercept	Slope	Kf	n	R2
UM-RH -0.5519	0.6227	0.28060797	1.605909748	0.8657
UM-OP -0.7241	0.4609	0.18875567	2.169668041	0.6645

The adsorption isotherm studies (in figure 4-8 and table 2 & 3) showed that both Langmuir and Freundlich models reasonably described mercury adsorption by the adsorbents. The Langmuir model produced correlation coefficients (R^2) of 0.8755 for UM-RH and 0.8123 for UM-OP, indicating favourable monolayer adsorption. The Freundlich model also showed good adsorption behaviour, particularly for UM-RH with R^2 value of 0.8657. The Freundlich constant n values greater than 1 indicate favourable adsorption intensity. Comparatively, UM-RH exhibited better adsorption performance than UM-OP, suggesting that rice husk possesses greater adsorption capacity for mercury removal due to its silica-rich composition and larger surface characteristics. These results are in tadem with the work of Abeokuta *et al*., (2025) [1]

Conclusion

In conclusion, the physicochemical assessment of River Niger water samples collected from Delta, Bayelsa, and Cross River States revealed that most of the measured parameters were within the World Health Organization (WHO) permissible limits for potable water. Parameters such as pH, conductivity, total dissolved solids, chloride, sulphate, nitrate, nitrite, fluoride, hardness, calcium, magnesium, sodium, and potassium indicated that the river water possesses relatively good chemical quality. The pH values showed that the water is slightly alkaline and suitable for aquatic and domestic purposes. Similarly, the low conductivity and total dissolved solids values suggest low salinity and minimal dissolved contaminants.However, turbidity, colour, iron, and manganese concentrations exceeded WHO recommended limits, indicating contamination of the river water. The extremely high turbidity and colour values may be associated with suspended particles, runoff, dredging, erosion, and unregulated mining activities occurring along the river. Elevated iron and manganese concentrations may also originate from geological weathering, industrial discharges, and corrosion of metallic substances. These elevated parameters make the water unsuitable for direct domestic consumption without adequate treatment.The adsorption studies further demonstrated that unmodified rice husk (UM-RH) and unmodified orange peel (UM-OP) are effective low-cost adsorbents for mercury removal from contaminated water. Optimum adsorption occurred at pH 5, contact time of 4 hours, and adsorbent dosage of 0.5 g. The adsorption efficiency increased with increasing contact time and adsorbent dosage. Both Langmuir and Freundlich isotherm models adequately described the adsorption process, with UM-RH showing better adsorption performance than UM-OP. Therefore, agricultural wastes such as rice husk and orange peel can serve as environmentally friendly and cost-effective materials for mercury remediation in polluted water systems.

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