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Remediation of Surface Water Polluted by Mining Effluent Discharges: Environmental Impacts and Treatment Methods in South-South Region, Nigeria

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Abstract. Heavy metals, including lead (Pb) and mercury (Hg), are highly toxic to both the environment and human health. Prolonged exposure to these metals can lead to significant health disorders. This study aimed to find an effective adsorbent to reduce Pb and Hg concentrations in water samples from South-South Region, Nigeria. The river was found to be highly turbid (average of 355 NTU), making it unsuitable for domestic use without treatment. The research tested modified rice husk (RH-TAM) and orange peels (OP-TAM) using tartaric acid. Results showed that the modified rice husk (RH-TAM) exhibited superior adsorption efficiency for Pb and Hg. Batch experiments were conducted to evaluate the removal efficiency of Pb and Hg using various adsorbents (modified and unmodified rice husk and orange peel). Factors such as pH, contact time, and adsorbent dosage were important in the sorption process. The optimal conditions were found to be pH 5, an adsorbent dosage of 0.5 g/20 ml, and a contact time of 4 hours at 35°C. Under these conditions, the highest Pb adsorption efficiencies were 75.56% for RH- TAM and 69.93% for unmodified rice husk (UM-RH). For Hg, RH-TAM achieved 53.26%, while UM-RH reached 45.11%. The adsorption efficiency of OP-TAM was 62.03% for Pb and 44.57% for Hg, with unmodified orange peel (UM-OP) showing the lowest efficiencies. The Langmuir isotherm better fitted the experimental data for both metals.

Keywords: Remediation, Surface Water, Pollution, Mining, Discharges South-South, Nigeria

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I. Introduction

Water is one of the most essential resources for sustaining life, playing a crucial role in ecological balance, economic activities, and human health. Across the globe, water bodies are under increasing stress due to anthropogenic activities, and in developing nations, mining has emerged as a significant threat to water quality (Ahluwalia & Goyal, 2005). The South-South region of Nigeria, rich in mineral resources, has witnessed a surge in mining activities over the past few decades, leading to extensive environmental degradation. This region, which includes states like Rivers, Akwa Ibom, Bayelsa, Cross River, and Edo, has been heavily impacted by mining operations that extract valuable minerals such as crude oil, natural gas, coal, and limestone (Itodo et al., 2021; Akacha et al., 2025). However, the environmental costs of these activities, particularly the pollution of surface water, have raised concerns about sustainability, human health, and biodiversity. Mining operations often involve the discharge of various effluents—wastewater laden with toxic chemicals, heavy metals, sediments, and other pollutants—into nearby rivers, streams, and lakes (Obruche et al., 2019; Odimgbe et al., 2026). These effluents, if not properly managed, can contaminate surface water sources, degrade aquatic habitats, and pose severe risks to the health of communities who depend on these water bodies for drinking, agriculture, and fishing (Jacintha et al., 2025). In the South-South region, the issue of surface water pollution due to mining discharges has become increasingly evident, with several rivers, including the Niger, Bonny, and Cross River, showing signs of contamination (Umudi et al., 2025).

Surface water pollution resulting from mining activities is not a new problem. However, the scale of the issue has grown substantially in recent years as mining activities intensify. The combination of industrial effluents, chemical runoff from mine tailings, and improper disposal of hazardous waste into water bodies has led to significant deterioration of water quality in many parts of the South-South region (Micheal et al., 2026). Not only do these pollutants affect the physical and chemical properties of water, such as turbidity, pH, and dissolved oxygen levels, but they also introduce a host of toxic substances into the environment, including heavy metals like mercury, lead, arsenic, and cadmium, which are highly toxic to both aquatic life and humans (Ekpo et al., 2025). The consequences of surface water pollution by mining effluents are far-reaching. Aquatic ecosystems, already fragile due to natural and anthropogenic stressors, become more vulnerable to disruptions. Loss of biodiversity, alteration of food chains, and the death of fish and other aquatic organisms are just some of the immediate impacts of contaminated water. For human populations living in proximity to mining sites, the health risks are equally alarming. Prolonged exposure to polluted water can lead to a range of diseases, from skin rashes and gastrointestinal disorders to more severe conditions like kidney damage, neurological disorders, and even cancer, depending on the type and concentration of pollutants involved. Addressing surface water pollution from mining effluent discharges requires urgent and effective remediation strategies. Remediation refers to the process of cleaning or mitigating the harmful effects of pollution on the environment. In the context of surface water, remediation aims to restore the quality of water bodies by removing contaminants, preventing further pollution, and ensuring that water resources are safe for consumption and ecological health (Olumuyiwa et al., 2012). There are various remediation techniques available, ranging from

physical methods like sediment removal and filtration, to chemical processes like neutralization and adsorption, and biological approaches that involve using plants or microorganisms to absorb or break down pollutants (Nathan et al., 2025). In the South-South region of Nigeria, efforts to address mining-related surface water pollution have been met with varying degrees of success. While some projects have focused on improving wastewater treatment processes at mining sites, others have sought to engage local communities in monitoring water quality and promoting sustainable mining practices (Erienu et al., 2022). However, the effectiveness of these strategies is often hindered by limited funding, weak enforcement of environmental regulations, and a lack of awareness among local populations about the dangers of mining-related water pollution. Moreover, the absence of comprehensive data on the extent and impact of pollution further complicates the development of effective remediation measures (Sarah et al., 2026). One of the key challenges in the remediation of polluted surface water in Nigeria's South-South region is the lack of proper waste management infrastructure. Many mining companies discharge untreated effluents directly into nearby rivers and streams without adequate treatment or containment, leading to widespread contamination (Umudi et al., 2025). Additionally, informal mining operations, often illegal, operate without regard for environmental standards, exacerbating the problem. This regulatory gap is compounded by the complex social, economic, and political realities in the region, where the demand for mineral resources often takes precedence over environmental protection (Etus & Obruche, 2026).

The Nigerian government, in collaboration with international organizations and non-governmental entities, has made some efforts to tackle mining-induced water pollution through legislation and policy initiatives. The National Environmental Standards and Regulations Enforcement Agency (NESREA) has implemented guidelines for effluent management and water quality monitoring. However, enforcement remains a significant challenge due to inadequate resources, corruption, and the dominance of informal mining practices. In addition, the existing legal frameworks often lack the specificity required to address the unique environmental challenges posed by mining activities in the South-South region (Obruche et al., 2025). Despite these challenges, there have been notable advancements in the development and application of various remediation technologies and approaches that could help mitigate the effects of mining effluent discharges on surface water quality. For example, phytoremediation, which involves the use of plants to absorb or degrade pollutants, has shown promise in restoring contaminated water bodies. Similarly, bioremediation, the use of microorganisms to break down hazardous substances, has been explored as an alternative to chemical treatments (Kehinde et al., 2025). These methods, although still in the early stages of development in Nigeria, offer sustainable, low-cost alternatives to traditional remediation techniques (Prasad et al., 2014; Moses et al., 2025). In conclusion, the remediation of surface water polluted by effluent discharges from mining activities in the South-South region of Nigeria is a complex and urgent issue that requires a multifaceted approach. Addressing this problem not only involves the application of technical solutions to remove pollutants but also requires a holistic understanding of the socio-economic and political dimensions of mining activities (Micheal et al., 2026). Effective remediation efforts will need to combine regulatory enforcement, technological innovation, and community involvement to ensure that surface water remains a safe and sustainable resource for both people and the environment.

II. Materials And Method

Experimental setup

This study was segmented into two primary sections. The initial section addresses the assessment of the physicochemical characteristics of water samples collected from the River Niger at Delta, Bayelsa, and Cross River State, comparing these to the WHO standards for potable water consumption levels. The subsequent section concentrates on the reduction of lead (Pb) concentrations in the water samples by utilizing agricultural waste as an adsorbent, as well as determining the optimal conditions for this adsorption process through batch testing (Okpanachi et al., 2025).

Sampling and Preservation.

The procedure for sampling and preservation adhered to the methodology established by Zhao et al., (2010) and Obruche et al. (2019). The water samples were gathered from the River Niger at Delta, Bayelsa, and Cross River State, located in the South South region of Nigeria. Sampling locations were selected near areas where small-scale mining operations occur, and the wastewater produced by these miners is discharged into the river. The samples were collected in airtight polypropylene bottles that had been cleaned and rinsed with distilled water. For heavy metal analysis, the samples were acidified with nitric acid upon collection to lower the pH to below 2. This is essential because maintaining a pH below 2 minimizes precipitation and adsorption to the container walls. Any acid could be utilized to oxidize the samples; however, HNO3 is preferred due to its oxidizing properties. The addition of HNO3 to the samples transforms the metal ions into their nitrate salts, which exhibit high solubility. Another significant reason for selecting HNO3 over other acids is that sample digestion is necessary prior to Atomic Adsorption Spectroscopic analysis, as this process aims to eliminate the matrix that could otherwise interfere during atomization. Digestion also ensures that all forms of the metal are converted into a single oxidation state. The remaining samples intended for physicochemical analysis were stored at temperatures ranging from 1 °C to 4 °C.

Adsorbent Collection.

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

Adsorbent Preparation

Preparation of Rice Husk and Orange Peel Adsorbents

This preparation was conducted in accordance with Ugochukwu, (2025) and Umudi et al.,(2026). The rice husk was thoroughly washed with distilled water. After cleaning, the rice husks were dried in an oven at a temperature of 50°C for a duration of 12 hours. They were then crushed using a mortar and pestle and sieved to achieve 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 procedure was followed for the orange peels, and the resulting product was placed in a clean airtight polypropylene bottle labeled UM-OP (Unmodified Orange Peel). A mixture was prepared by combining 5 g of the UM-RH with 35 ml of 1.2 M tartaric acid, which was stirred to create a homogeneous mixture. This mixture was then dried at 50°C for 12 hours and stored in a clean

airtight polypropylene bottle labeled RH-TAM (Rice Husk Tartaric Acid Modified). The same procedure was repeated for 5 g of UM-OP, and the resulting product was stored in a clean airtight polypropylene bottle labeled OP-TAM (Orange Peel Tartaric Acid Modified).

Standard Preparation

A standard solution of lead (Pb) was created from the 1000 mg/L reference solutions of Pb. 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 carried out according to the procedures described by (Obruche et al., 2018 and Umudi et al., 2025). Approximately 50 ml of the water sample from the Niger River was placed in a round-bottom flask, to which 5 ml of concentrated HNO3 (69%) was added. The mixture was boiled and evaporated on a hot plate until the volume was reduced to the lowest possible level (approximately 10 ml). After digestion, the flask was rinsed with distilled water and the mixture was filtered using 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 then analyzed for lead and mercury using the Atomic Absorption Spectrophotometer (AAS).

Batch Test

Variation of pH

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. 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. Subsequently, 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. The aforementioned procedure was also applied to RH-TAM and OP-TAM, modifying the method outlined by Abeokuta et al. (2025)

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; 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. Following this, 10 ml of each solution was digested (as previously described) and the filtrate was analyzed using AAS. This process was repeated for contact times of 1, 2, 3, and 5 hours. The entire procedure was repeated for both OP-TAM and RH-TAM, adhering to the methodology utilized by Ogwuche and Obruche (2020)

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. Following 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. The entire procedure was repeated for both OP-TAM and RH-TAM, following the methodology employed by Umudi et al., (1997).

Analysis of Lead Concentrations

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

Adsorption Isotherm

The water samples from the Birim River were spiked to achieve varying concentrations of both Pb and Hg, which ranged from 0.5 mg/L to 2.5 mg/L. The adsorption capacities of rice husk, orange peel, and their modified forms were evaluated 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 Pb and Hg adsorbed was calculated using the following equation:

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

In this equation, qe represents the adsorbent concentration once equilibrium has been reached. The variable V denotes the total volume of the solute solution (in liters), while Co indicates the initial concentration of the solute (in mg/L). The residual equilibrium concentration of the solute post-adsorption is represented by Ce (in mg/L), and 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.

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III. 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 Delta, Bayelsa and Cross River

RIVER NIGER					
PARAMETER		DELTA	BAYELSA	CRS	WHO
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 (NH_4-N) (mg/L)		0.11	0.114	0.109	0.00 – 1.5
Chloride (mg/L)		9.93	10.01	9.89	250
Sulphate(SO_4) (mg/L)		11.5	10.9	11.35	250
Phosphate (PO_4-P) (mg/L)		0.054	0.049	0.072	-
Manganese (mg/L)		0.496	0.501	0.508	0.4
Nitrite (NO_2-N) (mg/L)		0.013	0.013	0.012	1.0
Nitrate (NO_3-N) (mg/L)		0.116	0.115	0.113	10
Total Hardness (as $CaCO_3$)(mg/L)		46	44	48	500

Total Alkalinity (as $CaCO_3$) (mg/L)		26.4	26.5	27	-
Calcium Hardness (as $CaCO_3$) (mg/L)		18.6	18.6	18.9	-
Magnesium (as $CaCO_3$) (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	-

From the experimental findings for the three sampling stations presented in Table 1, it can be noted that the majority of the physicochemical parameters fall within the WHO guidelines for drinking water. Nevertheless, the levels of iron, turbidity, color, and manganese surpass the WHO standards for potable water. In the research conducted by O.D. Ansa-Asare and K.A. Asante titled "The Quality of Birim River in South-East Ghana" in 2000, similar observations of elevated turbidity were recorded from this river at Kibi (51.0 FTU), Kade (35.0 FTU), and Anyinam (19.0 FTU). The elevated turbidity levels may be linked to the unregulated mining activities occurring directly in this river. This is due to the fact that mining generates substantial quantities of sand, silt, and mud, which contribute to increased turbidity. Additionally, the chemicals utilized in these mining operations can precipitate and further elevate turbidity levels. The high color levels may result from the corrosion of metals such as lead (Pb) and copper (Cu). Consequently, the water requires treatment prior to its use for domestic purposes (Etus & Obruche, 2026).

Results from Batch Test

The outcomes derived from the batch test are illustrated graphically below, depicting the influence of contact time, pH, and adsorbent dosage on each adsorbent.

Effect of pH

The sorption of Pb by rice husk and orange peel adsorbents is contingent upon the pH of the solution Figure 1 generally indicates that the uptake of Pb is maximized at pH 6 for both modified and unmodified adsorbents. A similar study conducted by Obruche et al., (2018) demonstrated a higher adsorption of Pb at pH 5.3. However, as the pH increased, the quantity of Pb and Hg adsorbed diminished. This may be attributed to the fact that as pH rises, it causes the surfaces of the adsorbents and the metal ions to become negatively charged, resulting in repulsion rather than attraction. The modified adsorbents exhibit superior adsorption efficiencies compared to their unmodified counterparts. This enhancement could be due to the additional carboxyl and hydroxyl functional groups introduced by tartaric acid, which increased the adsorptive capacity.

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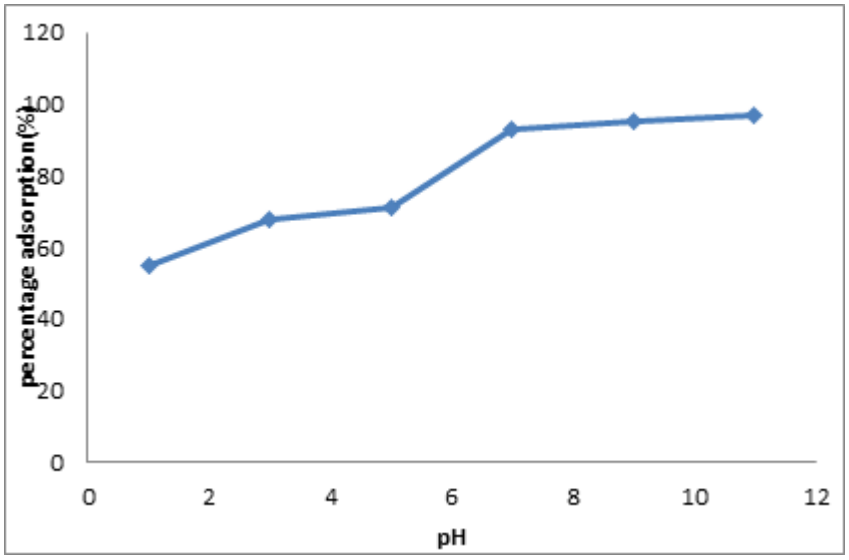

Figure 1: Effect of pH on RH-TAM, OP-TAM, UM-RH and UM-OP

Effect of Contact time

Figure 2 illustrates that the optimal duration for achieving maximum adsorption of Pb for both modified and unmodified adsorbents was 5 hours. The shortest duration for Pb adsorption was 1 hour. On average, the adsorption efficiency of the adsorbents improved as the contact time increased. A similar study conducted by Obruche et al., (2019) corroborated this observed trend. As the metal ions remained in contact with the adsorbent, an equilibrium was reached where the rate of bonding between the metal ions and the adsorbents equaled the rate of dissociation of the bond. At this stage, the adsorption efficiency of the adsorbent stabilized, showing no significant changes in adsorption; thus, the maximum adsorption of metal ions by the adsorbent was heavily influenced by the time at which equilibrium was attained.

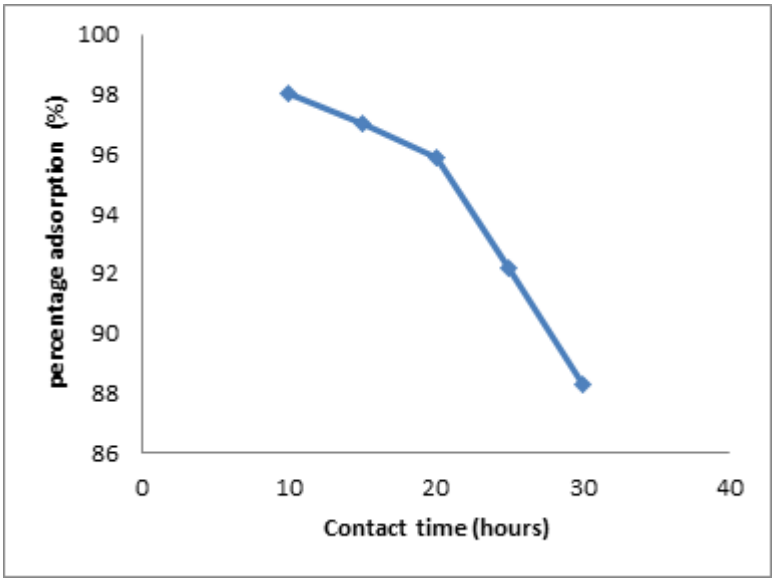

Figure 2: Effect of contact time on RH-TAM, OP-TAM, UM-RH, and UM-OP

Effect of adsorbent dosage

Figure 3 illustrates that the optimal dosage for achieving maximum Pb adsorption for both modified and unmodified adsorbents was 0.5 g. Conversely, the minimum dosage at which Pb adsorption was observed was also 0.5 g. In general, the adsorption efficiency of the adsorbents improved with an increase in adsorbent dosage, a finding corroborated by Ekpo et al., (2023), who conducted similar studies. The enhancement in adsorption efficiency relative to the increase in adsorbent dosage may be attributed to a rise in the surface area of the adsorbent, an increase in active functional groups, and consequently, a greater number of adsorption sites.

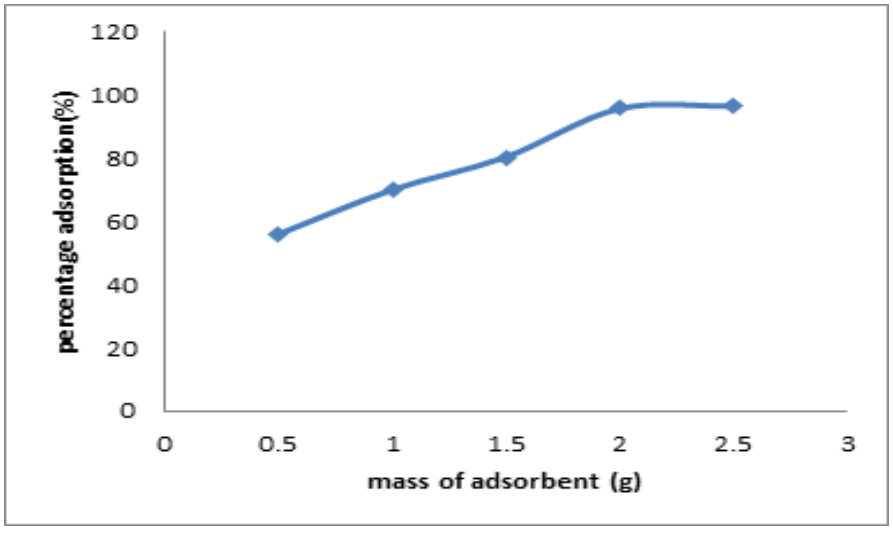

Figure 3: Effect of dosage on RH-TAM, OP-TAM, UM-RH and UM-OP

Adsorption Isotherms

Langmuir Adsorption Isotherm for RH-TAM
Figures 4 show Langmuir adsorption isotherms for RH-TAM for Pb.

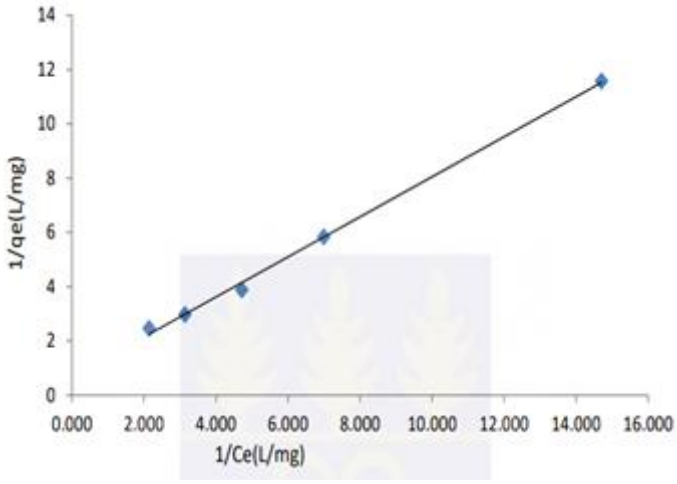

Figure 4: Langmuir isotherm for Pb adsorption using RH-TAM

Langmuir Adsorption Isotherm for UM-RH
Figures 5 show Langmuir adsorption isotherms for UM-RH for Pb.

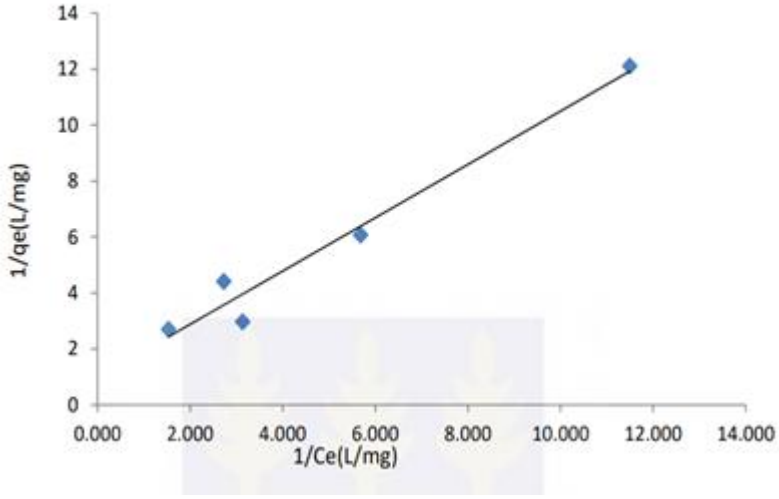

Figure 5: Langmuir isotherm for Pb adsorption using UM-RH

Langmuir Adsorption Isotherm for OP-TAM
Figures 6 show Langmuir adsorption isotherms for OP-TAM for Pb.

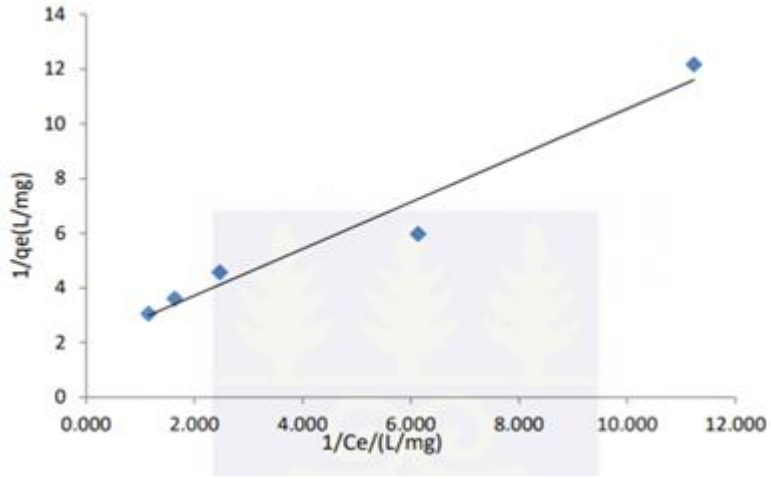

Figure 6: Langmuir isotherm for Pb adsorption using OP-TAM

Langmuir Adsorption Isotherm for UM-OP

Figures 7 show Langmuir adsorption isotherms for UM-OP for Pb.

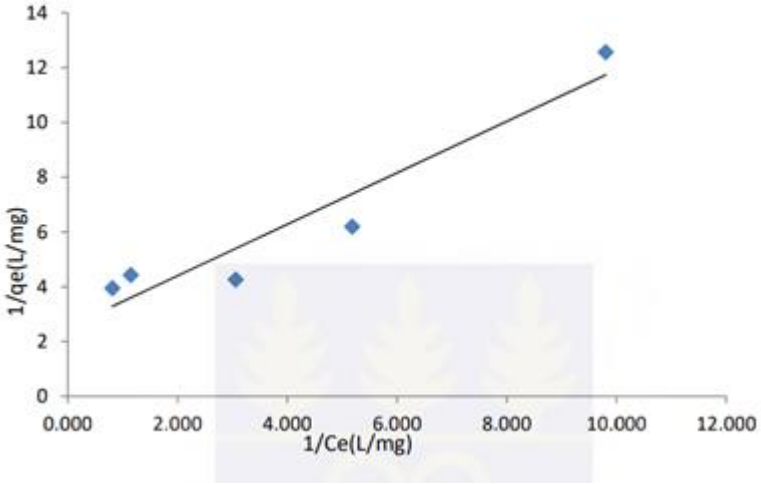

Figure 7: Langmuir isotherm for Pb adsorption using UM-OP

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Table 2. Langmuir isotherm parameters for Pb for RH-TAM, OP-TAM, UM-RH and UM-OP

Langmuir Isotherm for Pb adsorption for RH-TAM				
Intercept	Slope	qm (g/g)	Ka	R^2
0.5734	0.7466	1.74398326	0.768015	0.9989
Langmuir Isotherm for Pb adsorption for OP-TAM				
Intercept	Slope	qm	Ka	R^2
2.0073	0.8541	0.49818164	2.35019319	0.9599
Langmuir Isotherm for Pb adsorption for UM-RH				
Intercept	Slope	qm	Ka	R^2
0.9744	0.9521	1.02627258	1.02342191	0.9681
Langmuir Isotherm for Pb adsorption for UM-OP				
Intercept	Slope	qm	Ka	R^2
2.5224	0.9393	0.39644783	2.68540402	0.9136

Table 2 presented above indicates that the adsorption of Pb using RH-TAM aligns more closely with the Langmuir isotherm compared to the adsorption of Pb using UM-RH; this is evidenced by the R2 value for RH-TAM being nearer to one than that for UM-RH. In a similar manner, the adsorption of Pb with OP-TAM demonstrates a better fit to the Langmuir isotherm than the adsorption of Pb with UM-OP. The presence of additional functional groups (-COOH and -OH) from tartaric acid has enhanced the number of available adsorption sites in the modified adsorbent forms. This enhancement is reflected in the qm values (which represent the available adsorption sites) for all modified adsorbents. The primary functional group in UM-RH is SiO2. Likewise, the principal functional groups in UM-OP are -COO-H and -OH. The qm value for UM-RH (as shown in Table 2) surpasses that of UM-OP. Consequently, the adsorption efficiency of UM-RH exceeds that of UM-OP. Similarly, the qm value for RH-TAM is greater than that for OP-TAM; thus, RH-TAM exhibits a higher adsorption capacity than OP-TAM, which may be attributed to their relative bond stabilities concerning the metal ions.

Freundlich Isotherms

Freundlich Adsorption Isotherm for RH-TAM

Figures 8 show Freundlich adsorption isotherms for RH-TAM for Pb

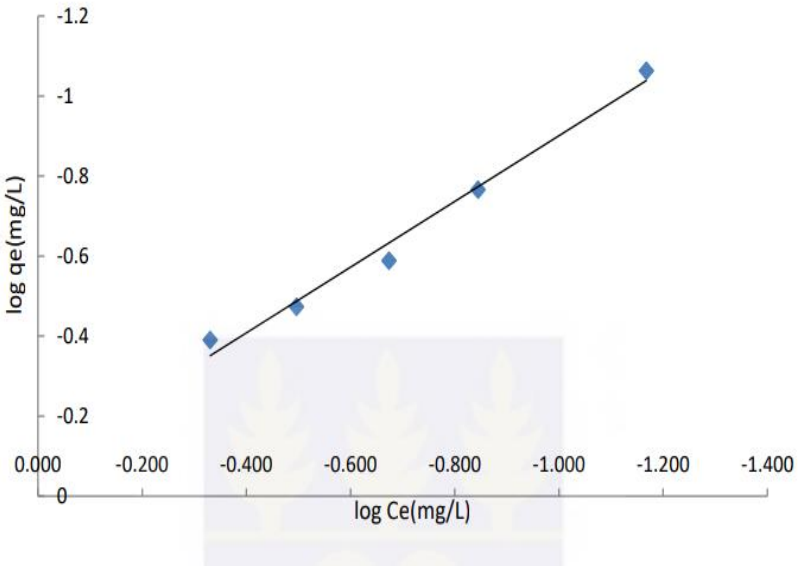

Figure 8: Freundlich isotherm for Pb adsorption using RH-TAM

Freundlich Adsorption Isotherm for UM-RH
Figures 9 show Freundlich adsorption isotherms for UM-RH for Pb.

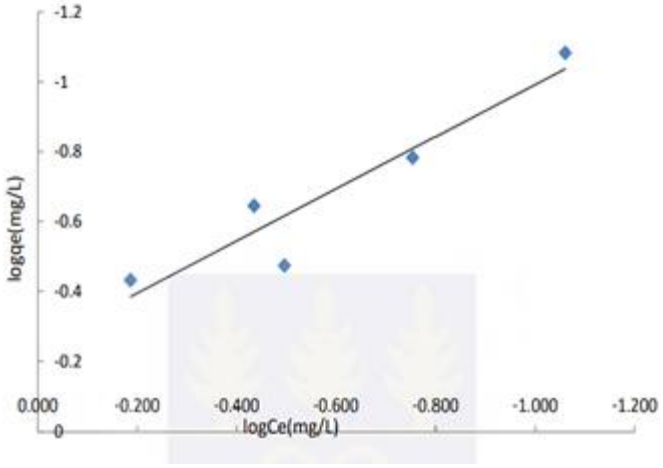

Figure 9: Freundlich isotherm for Pb adsorption using UM-RH

Freundlich Adsorption Isotherm for OP-TAM
Figures 10 show Freundlich adsorption isotherms for OP-TAM for Pb.

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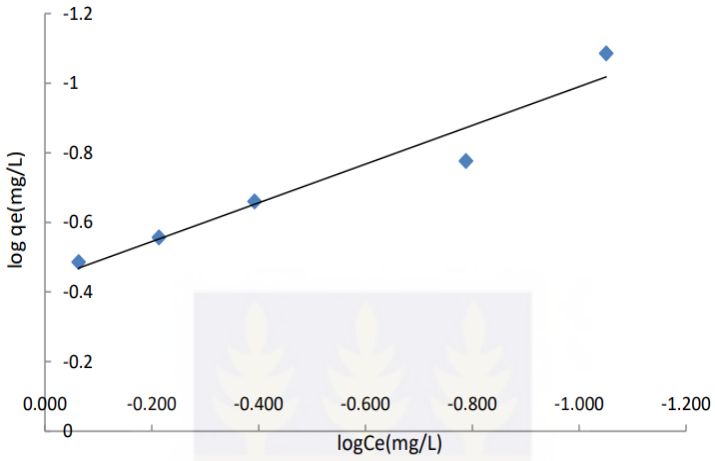

Figure 10: Freundlich isotherm for Pb adsorption using OP-TAM

Freundlich Adsorption Isotherm for UM-OP

Figures 11 show Freundlich adsorption isotherms for UM-OP for Pb.

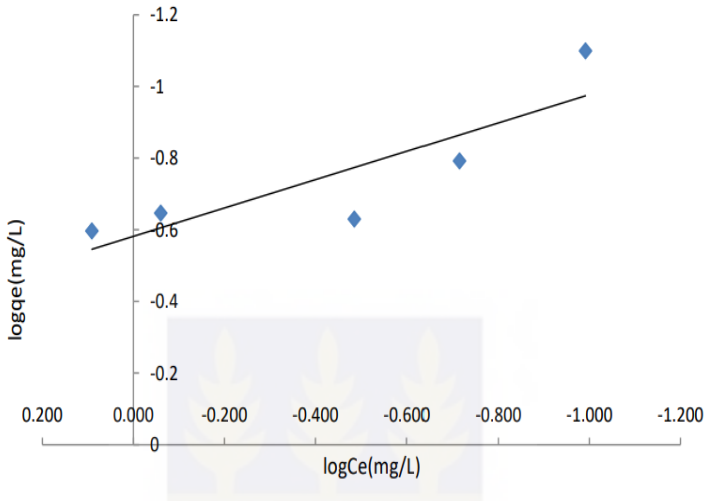

Figure 11: Freundlich isotherm for Pb adsorption using UM-OP

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

Freundlich Isotherm for Pb adsorption for RH-TAM				
Intercept	Slope	Kf	n	R^2
-0.0796	0.8212	0.8325 3021	1.2177 30151	0.9848
Freundlich Isotherm for Pb adsorption for OP-TAM				
Intercept	Slope	Kf	n	R^2
-0.4336	0.5563	2.7139 3849	1.7975 91228	0.9368
Freundlich Isotherm for Pb adsorption for UM-RH				
Intercept	Slope	Kf	n	R^2
-0.2452	0.7468	0.5685 9102	1.3390 46599	0.8892
Freundlich Isotherm for Pb adsorption for UM-OP				
Intercept	Slope	Kf	n	R^2
-0.5818	0.3957	0.2619 389	2.5271 67046	0.7337

Table 3 illustrates the Freundlich adsorption isotherm parameters for RH-TAM, OP-TAM, UM-RH, and UM-OP as determined for Pb. The R2 value for RH-TAM is nearer to 1 compared to that of UM-RH. Consequently, RH-TAM demonstrates a superior fit to the Freundlich model relative to UM-RH. The adsorption capacity (Kf) for RH-TAM surpasses that of UM-RH. Similarly, the adsorption capacity for OP-TAM exceeds that of UM-OP, as the Kf value for OP-TAM is higher than that for UM-OP. Ultimately, the Kf value for OP-TAM is greater than that for RH-TAM, indicating that the adsorption capacity for OP-TAM is also higher than that for RH-TAM.

IV. Conclusion

The adsorption of Pb by rice husk, orange peel, and their modified variants was examined under various conditions. RH-TAM achieved an adsorption capacity of 75.56%. The unmodified rice husk also demonstrated notable adsorption efficiencies of 69.92% for Pb. Although orange peel and its modified form were capable of adsorbing Pb, their efficiencies were lower in comparison to rice husk and its modified variant (i.e., OP-TAM-Pb: 62.03%, OP-TAM-Hg: 44.57%, UM-OP-Pb: 51.88%, and UM-OP-Hg: 42.39%). Overall, rice husk and its modified form displayed greater adsorption capacities than orange peel and its modified variant. Both adsorbents exhibited high adsorption efficiencies at a pH of 6, with an adsorbent dose of 0.5 g/20 mL for 4 hours at 35°C. The Langmuir adsorption isotherm yielded a better correlation for Pb adsorption than the Freundlich isotherm. The turbidity levels of water samples from the River Niger at Delta (356 NTU), Bayelsa (360 NTU), and Cross River State (350 NTU) signif-

icantly exceeded the WHO acceptable limit (5 NTU). Additionally, the initial concentrations of Pb (0.226 ppm) were also above the WHO acceptable limit of 0.01 ppm for Pb.

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