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Chemophysical and Metallic Characterization of Surface Water and Precipitation for Environmental Quality Assessment in Oyigbo L.G.A., Rivers State, Nigeria

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ABSTRACT

This study investigates the repercussions of oil industry operations on environmental quality in the Niger Delta, with a specific focus on atmospheric soot contamination. By conducting chemophysical and metallic characterization of surface water (river) and precipitation (rain) in Oyigbo, Rivers State, Nigeria, the research evaluates various chemical and physical parameters, like pH, electrical conductivity (EC), total suspended solids (TSS), turbidity, as well as concentrations of heavy metals like lead (Pb), copper (Cu), cadmium (Cd), and zinc (Zn). The findings uncover a slightly acidic to neutral pH in water samples. The elevated EC in the Imo River, while meeting WHO standards, highlights the delicate balance between industrial development and environmental health. Turbidity values, meeting WHO standards but exceeding limits in some rainwater samples, prompt scrutiny of

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anthropogenic influences, with fishing and sand mining emerging as potential contributors to river turbidity, while TSS values, though higher along the Imo River, remain within WHO standards. Results reveal Cd, Cu, and Zn adhere to standards, while the elevated Pb levels necessitate further exploration into contamination sources. The heavy metals pollution index (HPI) categorizes the area as polluted and identifies lead as the primary contributor, underlining the urgency of interventions. The potential ecological risks index (PERI) classifies the pollution risk as slight, indicating a low ecological risk level, and reveals risk hierarchies, in the order of metals contributing to pollution as Pb > Cu > Cd > Zn for both river and rainwater. This study unravels the relationship between industrial activities and water quality in Oyigbo, contributing substantively to sustainable water resources and environmental management. The detailed findings stand as a cornerstone for informed decision-making, aiming to mitigate environmental impacts and safeguard ecosystems and communities reliant on vital water sources.

Keywords: Heavy metal pollution; chemophysical analysis; water contamination assessment; environmental quality; Oyigbo; Rivers State; Nigeria.

1. INTRODUCTION

Freshwater, a critical and indispensable resource for life, faces escalating threats due to the growing populations and rapid industrialization, particularly in regions rich in petroleum resources, such as the Niger Delta in Nigeria [1,2]. The intricate interplay of natural processes and human activities significantly influences the quality of water in these areas [3]. When untouched by human influence, water quality is shaped by natural phenomena like weathering, evapo-transpiration, and biological interactions, resulting in the presence of various dissolved substances and particulate matter, essential for the health of aquatic ecosystems [4].

Gas flaring, a deeply entrenched practice in the Niger Delta, involves burning natural gases associated with crude oil extraction, often employed due to inadequate infrastructure for harnessing the released natural gas during oil exploration [5]. This practice contributes significantly to air pollution, with operations like gas flaring, oil spills, transportation, and illicit activities like oil theft and artisanal mining releasing substantial quantities of pollutants, particularly soot, into the atmosphere [6]. Precipitation, particularly rainwater, a vital component of environmental resources, undergoes chemical alterations as it traverses the atmosphere, incorporating these pollutants such as soot, trace elements, and heavy metals, consequently impacting its quality [7].
Water resources, encompassing precipitation water like rain, and surface water like rivers, face the direct substantial threats from anthropogenic activities like overexploitation and pollution, necessitating urgent measures for environmental sustainability [8,9]. Atmospheric soot, a prominent pollutant, influences the chemophysical properties of water, impacting its pH, temperature, dissolved oxygen, and various suspended and dissolved solids [10]. Additionally, soot significantly influences the presence and abundance of heavy metals, including cadmium, copper, lead, and zinc, offering crucial insights into the contamination status of both rainwater and surface water [6].

Environmental health assessment relies on various components to understand our ecosystem. These components, like chemical and physical parameters, including pH, total suspended solids (TSS), turbidity, electrical conductivity (EC), and heavy metal contents create a set of measures to evaluate the health of the environment including through the analysis of these parameters in water resources of any specific area [11]. Potential hydrogen or pH is a vital indicator influencing the solubility and movement of elements in water. It provides insights into the water's acidity or alkalinity, impacting aquatic life, nutrient availability, and overall chemical balance. pH significantly influences environmental health, affecting aquatic ecosystems and their inhabitants [12]. Both high and low pH levels can have adverse effects. High pH, indicating alkaline conditions, may disrupt nutrient availability, affect fish and invertebrates, and impact the aquatic food web. Conversely, low pH, indicating acidity, can lead to aluminum mobilization, nutrient limitations, and harm to aquatic life. Maintaining balanced pH is crucial for biodiversity, preserving relationships within ecosystems, and ensuring the well-being of diverse species relying on these environments [5].

TSS and Turbidity are indicators of water clarity, with increased levels signaling pollution and sedimentation, impacting light penetration, and disrupting aquatic habitats. Plants are affected through reduced sunlight for photosynthesis and compromised oxygen levels, harming plant health. For land animals, altered water quality and sedimentation pose threats to habitats and food sources. These parameters play pivotal roles in shaping environmental conditions, affecting ecosystems [13]. High TSS levels, indicating more solid particles, reduce light penetration, affecting aquatic plants' photosynthesis and disturbing habitats. Elevated turbidity, caused by suspended particles, reduces water transparency, and hinders fish foraging. These conditions challenge aquatic life, impacting resource availability. Moreover, the impacts extend beyond aquatic ecosystems, affecting plants, animals, and humans in the surrounding environment. Water clarity is crucial for sustaining a balanced ecosystem and ensuring the well-being of various species, both aquatic and terrestrial [14].

Electrical conductivity (EC) measures water's ability to conduct an electric current, often correlating with dissolved ion concentration, aiding in assessing salinity, nutrient levels, and overall water quality. It impacts the growth and survival of aquatic plants and animals. EC serves as a valuable indicator of dissolved mineral content and aquatic environment quality [15]. High EC suggests elevated concentrations of salts and minerals, affecting osmoregulation and metabolism in aquatic organisms. Low EC may indicate a lack of essential minerals, impacting nutrient availability. These variations cascade through aquatic ecosystems, influencing biodiversity. Beyond aquatic life, EC's influence extends to plants, animals, and humans in the surrounding environment. Maintaining balanced EC is vital for preserving intricate ecosystem relationships and overall environmental health [15].

Heavy metals like cadmium (Cd), a highly toxic heavy metal can accumulate in water bodies, posing serious threats to both human health and the environment. Chronic exposure to cadmium can lead to adverse health effects, including damage to the kidneys, lungs, and bones [6]. In plants, cadmium accumulation can disrupt nutrient uptake, impair growth, and ultimately impact the safety of food crops. This exposure has detrimental effects on plants, land animals, and humans, causing toxicity, developmental issues, and various health concerns. Lead (Pb), another heavy metal, has well-documented adverse effects on human health, especially affecting the nervous system, cognitive development in children, and cardiovascular health. Environmental exposure to lead can result from contaminated water, posing risks to aquatic life and potential bioaccumulation in the food chain [16]. Copper (Cu) and zinc (Zn), essential trace elements, require monitoring to prevent adverse effects on aquatic ecosystems from elevated concentrations. When accumulated, these heavy metals can lead to bioaccumulation in plants and animals, posing risks to both terrestrial and aquatic life. Excess copper can be toxic to aquatic organisms, affecting fish and invertebrates, while zinc, essential in small amounts, can become harmful in higher concentrations, impacting aquatic life and biodiversity [16].

Environmental quality parameters like potential ecological risks index (PERI) and heavy metals pollution index (HPI) offer consolidated measures, integrating factors like heavy metal concentrations to assess ecological risks and overall contamination levels in water bodies and the environment. Monitoring these factors is crucial for evaluating environmental health [17]. High values in the PERI and HPI suggest elevated contamination levels with heavy metals. These contaminants can have adverse effects on aquatic ecosystems, affecting the growth and reproduction of plants and animals [18]. Accumulation of heavy metals in organisms may pose health risks to humans and animals relying on these water sources. Lower values indicate reduced contamination, contributing to a healthier aquatic and terrestrial environment [19]. Understanding and managing these indices are essential for sustainable water resource management and mitigating the impact of heavy metal pollution on both aquatic and terrestrial ecosystems [20].

This study explores essential hydrochemical and hydrophysical parameters, by evaluating pH, TSS, EC, Turbidity, Zn, Pb, Cd, and Cu. Through indices like the HPI and PERI, the research endeavors to assess the environmental quality and contamination status of the study area. Focused on Oyigbo, Rivers State, Nigeria, the research specifically examines the chemophysical and metallic characteristics of both surface water (river) and precipitation (rain). The insights gained from this study not only address the environmental challenges faced by

Oyigbo but also have broader implications for regions grappling with similar issues. The research aims to be a catalyst for informed decision-making, promoting the well-being of ecosystems and the communities reliant on these vital water sources. As custodians of environmental well-being, assessing water resources using these parameters allows us to measure the resilience of ecosystems. This ensures the sustenance of aquatic life, protects biodiversity, and safeguards the overall health of our environment. Embracing this approach emphasizes the collective significance of these indicators in guiding responsible environmental management.

1.1 Study Area

1.1.1 Description of the study area

Oyigbo, located in the Niger Delta region of Nigeria, serves as both a town and a Local Government Area in Rivers State. Positioned approximately 30 kilometers northeast of Port Harcourt, its geographic coordinates range from latitude 4˚54' to 4˚46' N and longitude 7˚15' to 7˚25' W, covering a total area of 248.00 km² (95.75 sq mi) (Fig. 1). Established in 1991, Oyigbo Local Government Area, with its administrative headquarters in Afam (Okoloma-Ndoki), was carved out of Khana/Oyigbo Local Government. It shares borders with Khana to the Southeast, Tai to the South, Eleme and Obio/Akpor to the Southwest, and is bounded by Abia State to the North [21].

The region is divided into two zones inhabited by the Asa and Ndoki people. As a pivotal sociopolitical and economic player in Rivers State, Oyigbo contributes to the cultural and environmental richness of the Niger Delta. Rivers State, surrounded by Imo, Delta, Akwa Ibom, Abia, and Bayelsa States, stands at the core of the Niger Delta, known for its diverse cultural tapestry. Oyigbo, a hub of ethnic vibrancy within

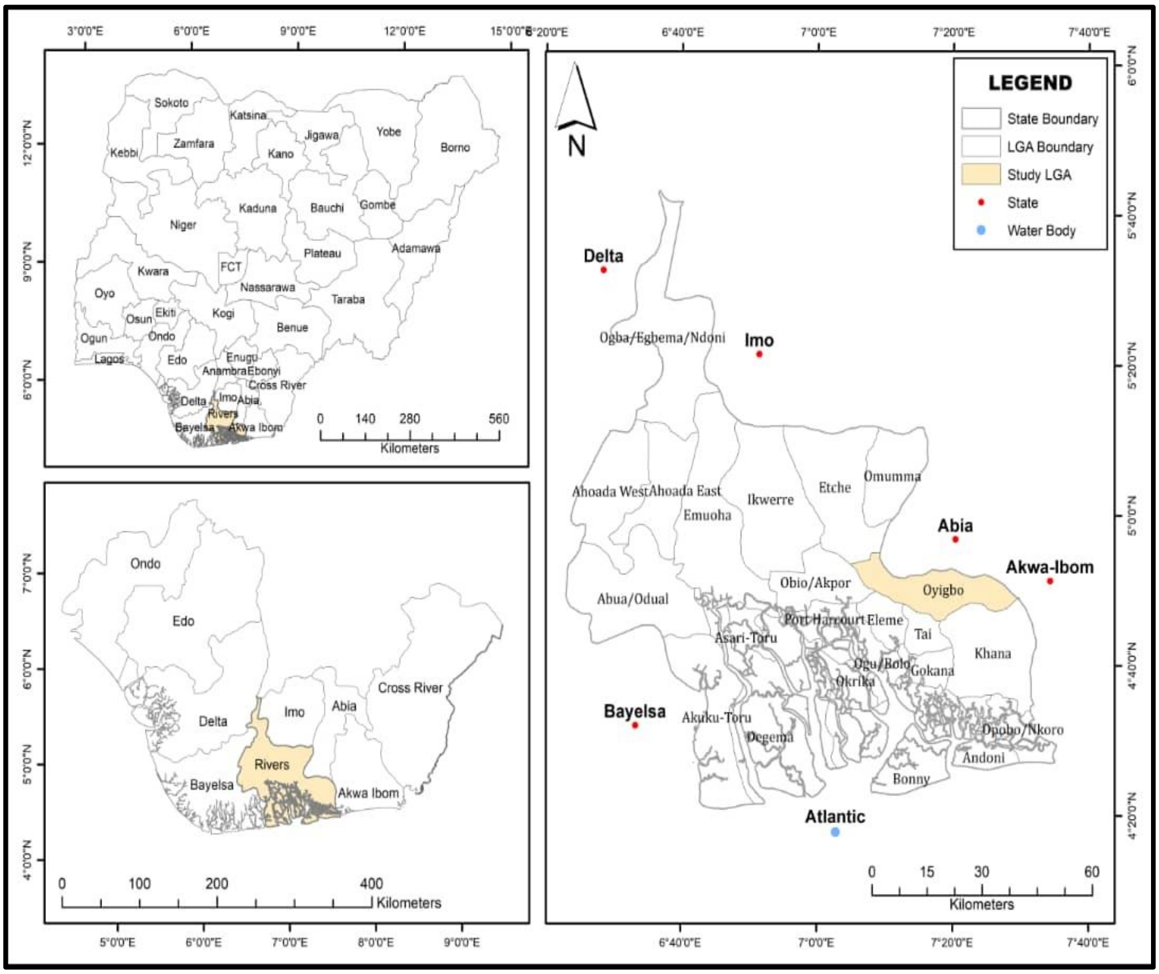

Fig. 1. Map of rivers state showing the study area

(Source: Digitized by Author)

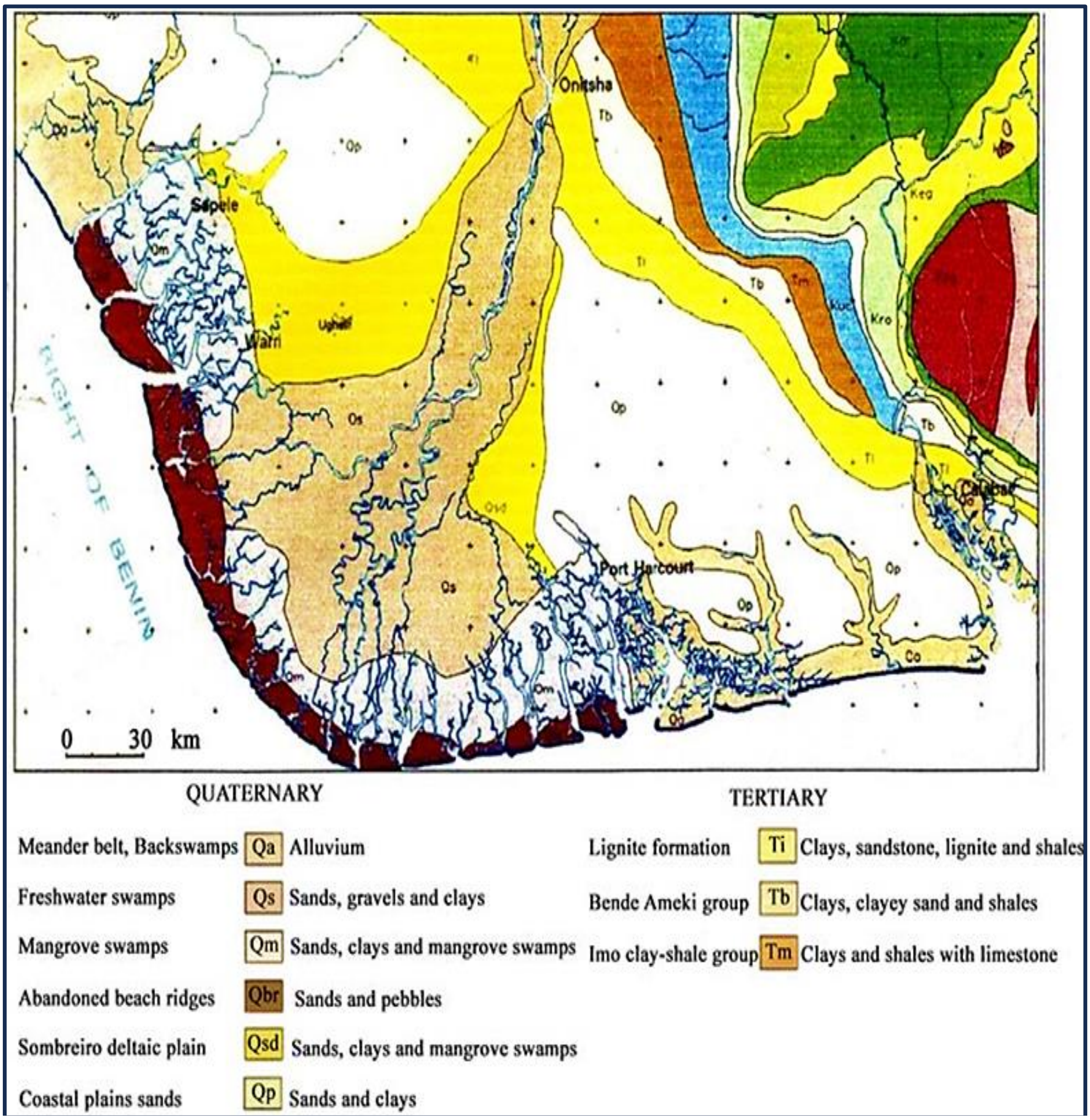

Fig. 2. Geological Map of the Niger Delta
(Source: [29])

Rivers State, hosts communities representing various ethnicities, with the Ikwerre people as the predominant group. The Oyigbo Local Government Area is further divided into two main regions, Asa and Ndoki, and has experienced a notable demographic increase from 40,407 in 1975 to 125,666 in 2015. This growth is associated with a rise in population density, reflecting the unique terrain and abundance of dry land. The population distribution in 2015 comprises 63,575 males and 62,091 females, providing insights into the socio-economic and environmental dynamics shaping Oyigbo within the broader context of Rivers State [22].

1.2 Hydrology and Geology of Study Area

The Oyigbo area experiences a tropical wet climate with prolonged rainy seasons and a brief dry season from November to February. Notably, September receives the heaviest precipitation, averaging 370 mm, while December is the driest month with 20 mm of rain [23]. Temperature variations are minimal, ranging between 25°C and 28°C throughout the year. Relative humidity is around 80 percent during the rainy season and drops to approximately 40 percent in the dry season. Oyigbo, located in the equatorial rainforest belt, has a monthly mean temperature of 25 to 28.5°C and an annual rainfall of about

2500 mm, mainly occurring between May and October [23,24].

The area's topography is characterized by sub-horizontal and gently sloping terrain, and the dominant vegetation is tropical rainforest. The region faces poor drainage due to low relief, a high-water table, and intense rainfall, leading to seasonally flooded areas impacting agriculture and development. The coastal plain, with an elevation of about 139m above sea level, comprises low-lying plains, swamps, creeks, and waterways. The Imo River, originating in Umuaku village, is a significant water resource in Oyigbo, supporting the daily activities of communities along its banks and tributaries. The river flows through three main tributaries (Aba River, Otamiri River, and Oramirukwa River) and empties into the Atlantic Ocean through wide estuaries in Rivers State, covering 40km in width with an average discharge of 4000m^3/s and 26,000 hectares of wetland. The Imo River spans four states: Abia, Imo, Rivers, and Akwa Ibom. Its coordinates are within Latitude 4°28 ’14″N and Longitude 7°35’38 W [25].

The geological map of the Niger Delta (Fig. 2), shows the three significant sub-surface lithostratigraphic units in the examined region, arranged sequentially from top to bottom as the Benin Formation, Agbada Formation, and Akata Formation. These formations are covered by Quaternary to Recent alluvial deposits known as the Sombreiro-Warri Deltaic Plain sands, comprising sandy silt, brownish lateritic soils, and fine to medium/coarse-grained unconsolidated sands [26]. The Sombreiro-Warri Deltaic Plain sands generally do not exceed 120 m in thickness and are predominantly unconfined, with an additional lateritic unit ranging from 4 to 5 m in thickness. The Benin Formation, a continental Eocene to Recent deposit, consists of friable sands with shale clay lenses, reaching thicknesses of up to 2000 m [27]. This formation serves as the primary freshwater source in the region. Beneath the Benin Formation, the Agbada Formation exhibits alternating sandstone and shale layers, originating from the interface between the lower deltaic plain and marine sediments [28].

The Agbada formation, formed from the Eocene to the Recent era, it boasts a thickness exceeding 3700 m and serves as the primary petroleum reservoir, hosting most hydrocarbon accumulations in the Niger Delta. Hydrocarbons are trapped in rollover anticlines formed by growth faults during sediment deposition [28]. The underlying Akata Formation, ranging from Paleocene to Recent, comprises shale, potentially serving as a source rock, along with silty and sandy layers. This formation, estimated to be up to 7000 m thick, covers the entire delta and is characterized by overpressure. It formed during periods of low sea level, transporting terrestrial organic matter and clays to deep water areas with low-energy conditions and oxygen deficiency. Limited drilling has taken place in this formation [29].

2. MATERIALS AND METHODS

2.1 Fieldwork and Sampling

The comprehensive study involved a meticulous analysis of a total of 41 water samples, comprising 34 rainwater samples and 7 surface water samples, collected from various locations within the Oyigbo region of Rivers State, Nigeria (Table 1, and Fig. 3). The rainwater collection process was executed in real-time using a purpose-built rainwater harvesting system, strategically positioned on power grid poles to ensure a random yet uniform distribution across the study area. The surface water samples were directly obtained from community rivers, and the sampling locations were systematically categorized into five study axes: Obigbo, Komkom-Obiama, Okoloma, Egberu, and Umu Agbai-Obete. To enhance the precision and reliability of the study, each sampling point was meticulously geo-referenced using a Garmin eTrex 32x, a rugged Handheld Global Positioning System (GPS). Additionally, on-site visual field observations were conducted and diligently recorded in a field notebook. This approach aimed to ensure a thorough and well-documented sampling process, laying a foundation for subsequent laboratory analyses. The fieldwork was conducted with precision during the last quarter of 2021 and the first quarter of 2022, signifying a detailed and timely data collection process. The sampling across different axes not only contributed to the accuracy of sample identification but for the precision of the subsequent laboratory analysis.

Table 1. Rain and river water sample location points

Sample Number	**Study Axis**	**Sample Location**	**Sample Type**	**Sample ID**	**Coordinates**	
					Latitude (N)	**Longitude (E)**
SN 1	**Obigbo**	Model Primary Health Care Centre	Rain	HSP 1	4° 52' 34.7984"	7° 06' 48.9204"
SN 2		Timber Market	Rain	MKT 1	4° 52' 23.4361"	7° 07' 03.3718"
SN 3		Obigbo Main Market	Rain	MKT 2	4° 52' 41.7036"	7° 08' 44.7853"
SN 4		Atata Market / Express Bus Stop Area	Rain	MKT 3	4° 53' 01.5396"	7° 07' 50.0344"
SN 5		Umuebele Market	Rain	MKT 4	4° 53' 55.7502"	7° 08' 11.1926"
SN 6		Community Secondary School, Umundinor	Rain	SCH 1	4° 52' 53.0860"	7° 07' 36.2982"
SN 7		Community Secondary School, Umuakpahu	Rain	SCH 2	4° 52' 55.8332"	7° 07' 36.0624"
SN 8		Oasis of Love Orphanage Settlement	Rain	SET 1	4° 53' 32.2656"	7° 06' 29.9628"
SN 9		Shell Flow Station Umuebele 4	Rain	FCLT 1	4° 53' 31.9279"	7° 07' 21.5270"
SN 10		Otamiri River – Umuebele 1	River	RVR 1	4° 54' 11.6281"	7° 08' 26.3642"
SN 11		Otamiri River – Umuebele 2	River	RVR 2	4° 54' 18.2052"	7° 08' 22.0704"
SN 12		Imo River – Obigbo/Abia Bridge	River	RVR 3	4° 53' 22.0646"	7° 08' 41.4646"
SN 13	**Komkom-Obiama**	Konko Market	Rain	MKT 5	4° 51' 22.8564"	7° 10' 56.0604"
SN 14		Community Secondary School, Komkom	Rain	SCH 3	4° 51' 28.0440"	7° 10' 31.0296"
SN 15		Lekuma-Obiama Settlement	Rain	SET 2	4° 51' 05.1120"	7° 11' 36.7692"
SN 16		Komkom Settlement	Rain	SET 3	4° 51' 28.2340"	7° 09' 33.6122"
SN 17		Obiama Settlement	Rain	SET 4	4° 50' 30.9264"	7° 11' 38.3784"
SN 18		Imo River – Obiama	River	RVR 4	4° 51' 33.1020"	7° 11' 45.8196"
SN 19	**Okoloma**	Okoloma Market	Rain	MKT 6	4° 50' 59.6040"	7° 14' 45.1680"
SN 20		Umuosi Market	Rain	MKT 7	4° 51' 47.6820"	7° 17' 52.4328"
SN 21		Ayama Settlement	Rain	SET 5	4° 51' 09.7200"	7° 15' 51.0840"
SN 22		Afam Settlement / Roundabout Area	Rain	SET 6	4° 51' 04.5000"	7° 14' 15.0360"
SN 23		Obumku Settlement	Rain	SET 7	4° 51' 33.0120"	7° 16' 54.4080"
SN 24		Okoloma Gas Plant	Rain	FCLT 2	4° 50' 40.2182"	7° 15' 12.6145"
SN 25		Afam Power Plant	Rain	FCLT 3	4° 50' 53.4408"	7° 15' 24.7500"

Sample Number	Study Axis	Sample Location	Sample Type	Sample ID	Coordinates	
					Latitude (N)	Longitude (E)
SN 26		Imo River – Okoloma	River	RVR 5	4° 51' 11.6640"	7° 13' 27.6132"
SN 27	**Egberu**	Ndoki Health Care Centre	Rain	HSP 2	4° 51' 07.6284"	7° 19' 06.1212"
SN 28		Ndoki Market	Rain	MKT 8	4° 50' 56.6016"	7° 19' 36.9012"
SN 29		Ndoki Comprehensive School	Rain	SCH 4	4° 50' 59.5212"	7° 19' 27.8616"
SN 30		Afam-Uku Settlement	Rain	SET 8	4° 49' 00.0120"	7° 19' 00.0120"
SN 31		Egberu-Ndoki Settlement	Rain	SET 9	4° 48' 35.3562"	7° 16' 48.6335"
SN 32		Afam-Nta Settlement	Rain	SET 10	4° 48' 24.8508"	7° 20' 32.4888"
SN 33	**Umu Agbai-Obete**	Ban-Lori Market	Rain	MKT 9	4° 48' 22.7520"	7° 25' 55.2720"
SN 34		Obete Settlement	Rain	SET 11	4° 48' 39.4920"	7° 29' 14.0640"
SN 35		Umu Agbai Settlement	Rain	SET 12	4° 51' 12.3480"	7° 22' 38.5680"
SN 36		Okpontu Settlement	Rain	SET 13	4° 50' 05.7480"	7° 27' 31.8240"
SN 37		Azuagu Settlement	Rain	SET 14	4° 50' 51.3564"	7° 23' 35.3868"
SN 38		Marihun Settlement	Rain	SET 15	4° 50' 46.5900"	7° 25' 22.3824"
SN 39		Azumini Settlement	Rain	SET 16	4° 49' 07.4748"	7° 28' 29.6976"
SN 40		Imo River – Umu Agbai	River	RVR 6	4° 51' 27.9180"	7° 22' 19.8588"
SN 41		Imo River – Okpontu	River	RVR 7	4° 50' 35.8152"	7° 27' 01.5552"

2.2 Field Tests and Laboratory Analysis

Various water quality parameters were analyzed using specific methods. The concentrations of Cadmium (Cd), Lead (Pb), Copper (Cu), and Zinc (Zn) were determined using atomic absorption spectroscopy. pH was measured with a standard pH meter, and turbidity was assessed through the photometric method. Total suspended solids (TSS) were measured in-situ using appropriate standard meters in the field. The electrical conductivity (EC) was determined with an EC meter after a proper calibration process using standard solutions. The methods employed ensured a comprehensive analysis of water quality and accurate evaluation of the environmental conditions at the sampling sites. Table 2 shows the analytical methods used for rain and river water samples analysis.

2.2.1 Chemophysical analysis

The analysis for pH involved powering on the pH meter for at least 30 minutes before testing and preparing buffer solutions with pH values of 4.0, 7.0, and 9.0. Calibration of the pH meter was performed successively to 9.2, 7.0, and 4.0 using the respective buffers. The sample's pH was then measured by inserting it into the pH meter. Total Suspended Solids (TSS) determination employed photometric methods with an HACH DR/2010 spectrophotometer, utilizing a blank of filtered deionized water for zeroing. After shaking the sample and pouring 25 ml into a sample cell bottle, the TSS value was digitally displayed in mg/l. For Electrical Conductivity (EC) measurement, the EC meter was powered on for at least 30 minutes, calibrated with standard solutions, and adjusted at successive points using the calibration knob. The sample's electrical conductivity was then measured, considering temperature compensation. Turbidity assessment utilized a photometric method with an HACH DR/2010 spectrometer, zeroing with a 250 ml blank of filtered de-ionized water. After shaking the sample and pouring 25 ml into a sample cell bottle, the turbidity value was digitally displayed in mg/L.

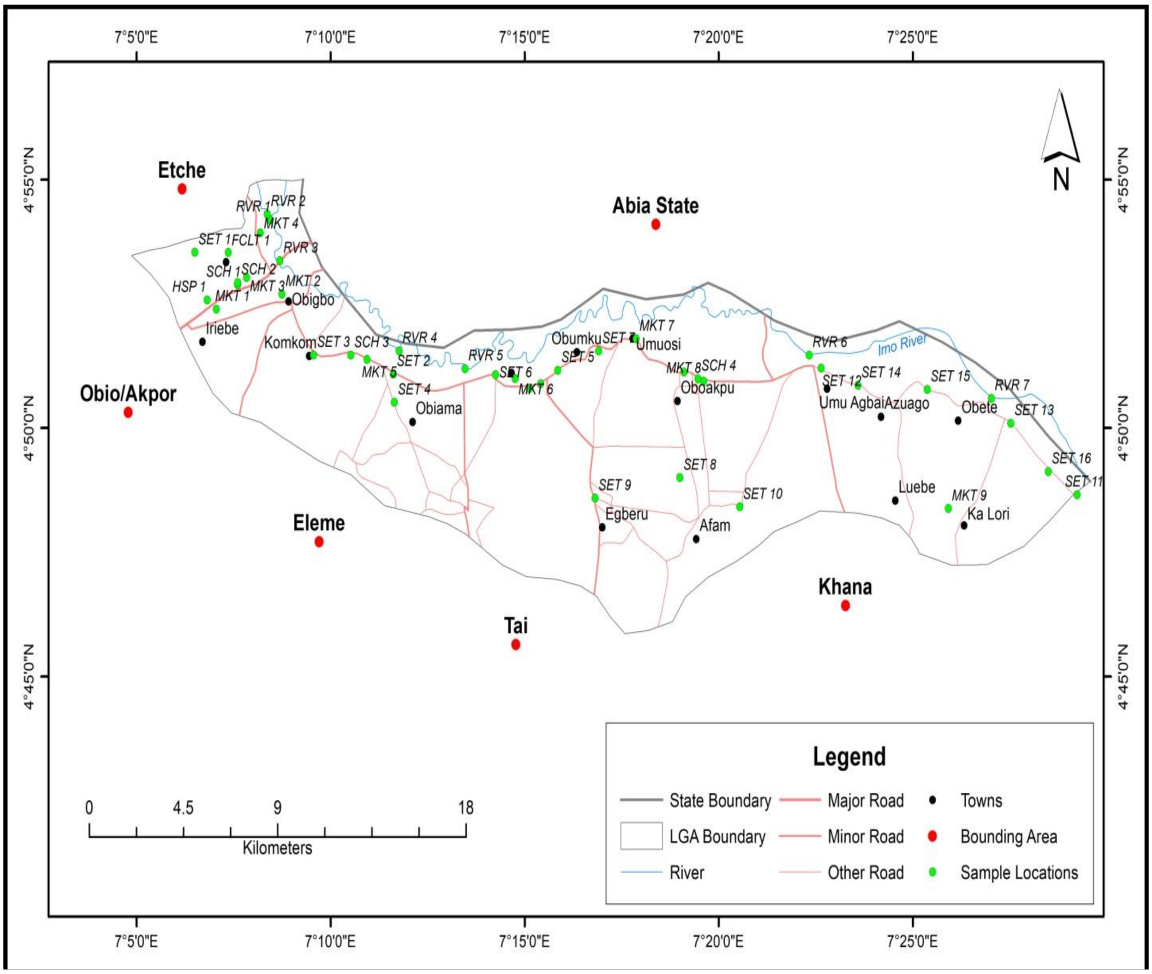

Fig. 3. Sampling points for the study area
(Source: Digitized by Author)

Table 2. Analytical methods used for surface and rainwater samples analysis
(Source: [20])

Class	Parameter	Symbol	Unit	Type of Test	Guidelines / Standard
Chemophysical parameters	pH	pH		In-situ	ISO 10523:2012
	Total Suspended Solids	TSS	mg/l	In-situ	ISO 702:2016
	Electrical Conductivity	EC	uS/cm	In-situ	ISO 7888:1985
	Turbidity	Tb	NTU	In-situ	ISO 7027
Heavy Metals	Zinc	Zn	mg/l	Laboratory	APHA 3111B
	Lead	Pb	mg/l	Laboratory	APHA 3111B
	Cadmium	Cd	mg/l	Laboratory	APHA 3111B
	Copper	Cu	mg/l	Laboratory	APHA 3111B

2.2.2 Heavy metal analysis

The heavy metals analyzed in this study included Cadmium (Cd), Lead (Pb), Copper (Cu), and Zinc (Zn). The determination of these heavy metals was carried out using an Atomic Absorption Spectrometer (AAS). For water digestion in preparation for heavy metal analysis, 50 ml of the sample was digested in a 250 ml conical flask by adding 10 ml of aqua regia. The mixture was heated on a hot plate until the volume reduced to about 7-12 ml. The resulting digest was filtered using Whatman filter paper, and the volume was adjusted to the mark in a 50 ml volumetric flask. The filtered solution was then stored in a plastic container for subsequent AAS analysis. The AAS works on the principle of aspirating the sample into a flame, where it is atomized. The AAS's light beam passes through the flame into a monochromator and onto a detector that measures the amount of light absorbed by the atomized element. Since metals have their characteristic absorption wavelength, a source lamp composed of that element is used, making the method relatively free from spectral or radiational interferences. In the procedure, the sample is thoroughly mixed, and 100 ml of it is transferred into a 250 ml glass beaker. The sample is then aspirated into either an oxidizing air-acetylene flame or a nitrous oxide acetylene flame, and the sensitivity for 1% absorption is observed when aqueous samples are aspirated.

2.3 Pollution Level and Ecological Risk Assessment of Heavy Metal

2.3.1 Heavy Metal Pollution Index (HPI)

HPI was used to determine the total quality of water with respect to heavy metals. This was first proposed by Mohan et al., [30]. The HPI is based on assigning a weight (W_i) for individual parameter which is a value between zero and one. This reflects the relative importance of the individual quality consideration, and it is calculated according to Equation 1, and 2.

Unit weight $(W1) = \frac{K}{S1}$ -------------- (1)

Where:

K = 1; W_1 is the unit weight factor; k_1 is a constant; S_1 is standard permissible limit of the i^{th} parameter.

Part two; Q= $\sum_{i=1}^{n} \frac{\{Mi(-)Ii\}}{(S1-Ii)} \times 100$ ------- (2)

Where:

Q_1 is the sub-index value of the i^{th} parameter; Mi is the monitored value; Ii is the ideal value and Si is the standard of the i^{th} parameter.

The negative sign (-) is the numerical difference of the two values, the algebraic sign is ignored.

For this index, the intended use is for drinking hence the critical pollution index value is 100 as demonstrated in Equation 3.

HPI = $\frac{\sum_{i=1}^{n} W1Q1}{\sum_{i=1}^{n} W1}$ --------------------------- (3)

Where:

Qi is the sub-index of i^{th} parameter. Wi is the unit weight age for ith parameter, n is the number of parameters considered.

The calculation of the river water samples (7), and rainwater samples (34) is carried out in Microsoft excel and reported using the format presented by Table 3, and 4.

2.3.2 Potential Ecological Risk Index (PERI)

The ecological risk assessment utilized in this study, developed by Hakanson [18], aimed to evaluate the ecological and environmental risk posed by heavy metal pollution in surface water. This method incorporates factors such as toxicity level, synergy, heavy metal concentration, and ecological sensitivity [19]. The calculation of the Potential Ecological Risk Index (PERI) involves fundamental modules, including the degree of contamination (CD), toxic-response factor (TR), and potential ecological risk factor (ER) [18]. Following this method, the potential ecological risk index for a single element (EiR) and the overall potential ecological risk index (RI) are determined according to Equation 4, 5, and 6.

$C_f{}^{i} = C_D^i / C_R^i$ --------------------------- (4)

$Ei_R = T_R^i \times C_f^i$ ---------------- (5)

$Ri = \sum_{i=1}^{m} E_R^i$ ---------------- (6)

Illustration:

C_D^i is the analyzed heavy metal concentration from each sample location.

C_R^i is the reference value, or back-ground value of each heavy metal analyzed.

Equation (3.09) is the pollution of a single element factor.

E_R^i is the potential ecological risk index of a single element.

RI is a comprehensive potential ecological risk index and T_R^i is the toxic response factor of an *ith* element. This factor is represented as Zn = 1, Cu = 5, Pb = 5 and Cd = 30 [18]

The ecological risk levels are classified as shown in Table 5.

3. RESULTS AND DISCUSSION

Hydrochemical characterization of 41 water samples, encompassing surface water and rainwater (Table 6), was conducted to assess contamination. The analysis involved interpreting the results against established background values to identify any deviations and discern their potential causes and sources. Presentation of findings employs tables and graphs, followed by a quantitative discussion. The outcomes not only contribute valuable insights to the topic but also pave the way for future qualitative research in both the subject matter and the study area.

3.1 Chemophysical Parameters

3.1.1 pH

The pH of water refers to its level of acidity or alkalinity on a scale from 0 to 14, where 7 is considered neutral. pH values below 7 indicate acidity, while values above 7 indicate alkalinity. pH is a fundamental parameter that helps to measure the balance between acidic and alkaline substances present in water. From Table 6, the pH values for river water samples were within the range of 5.9 to 6.8 (Fig. 4a). While the values of rainwater samples show that Obigbo axis ranged from 4.79 to 6.55, Komkom-Obiama Axis from 4.63 to 6.35, Okoloma Axis from 5.55 to 6.48, Egberu Axis from 5.98 to 6.65 and Umu Agbai-Obete axis from 5.56 to 6.84 (Fig. 4b).

This result therefore indicates that the river water samples were within the World Health Organization [32] and Nigerian Standards for Drinking Water Quality [33] while majority of the rainwater samples at the 5 axes were below WHO Standard. The pH of the area showed a slightly acidic to neutral environment. This could be because of the dissolution of minerals by the atmospheric CO_2 from the heavy industries in the area and a major petrochemical industry the Indorama Eleme petrochemical industry, one of the largest producers of olefins and polyolefin plastics which is located at a very close proximity to the study area at Eleme (south of the area). An expression of the reaction shows that excess H^+ ion from the partial reaction which is left in the water solution causes HCO_3^- in the rainwater to be significant. HCO_3^- resulted, and this significantly lowered the pH of the southwestern part of the study area.

3.1.2 Electrical Conductivity (EC)

Conductance serves as a qualitative indicator of inorganic pollution, reflecting the presence of total dissolved solids and ionized species in water [34,35]. Typically, surface waters with elevated concentrations of dissolved ions, including calcium, magnesium, sodium, and chloride, exhibit higher conductivity [15]. Rainwater, initially characterized by very low conductivity as essentially distilled water, undergoes an increase in conductivity due to contact with the atmosphere and surfaces, leading to the incorporation of dissolved substances like gases, atmospheric dust, and pollutants [15,36].

The recorded electrical conductivity (EC) values for river water samples ranged from 97 to 158 µS/cm (Fig. 5a). Rainwater samples exhibited varying EC values across different axes: Obigbo (6.55 to 61.45 µS/cm), Komkom-Obiama (18.22 to 50.35 µS/cm), Okoloma (5.79 to 102.45 µS/cm), Egberu (8.4 to 55.5 µS/cm), and Umu Agbai-Obete (8.74 to 47.06 µS/cm) (Fig. 5b).

The EC values for river water and rainwater samples as shown in Figure 5a and 5b revealed higher conductivity values were found at the course of the Imo River where samples were taken, while lower values are seen at the southern part of the study area and were observed to be within the acceptable limits of WHO standard [32] respectively. Generally, surface waters with higher concentrations of dissolved ions, such as calcium, magnesium, sodium, and chloride, tend to have higher conductivity [15]. While rainwater generally starts with very low conductivity because it is essentially distilled water [15].

Table 3. Calculation of the HPI of river sample
(Source: [30])

River 1	**PPb (μg/L)**	**BIS /WHO STD**	**μg/l= mg/l*1000**								
Heavy Metal	**STD PERM LIMIT (Si)**	**Ideal Value (Ii)**	**Montd Value (Mi)**	**UNIT WT (Wi)**	**Mi-Ii**	**{Mi-Ii}**	**Si-Ii**	**Qi={Mi-Ii}/(Si-Ii) *100**	**WiQi**	**∑Wi**	**HPI**
Cd	5	3	2.9	0.2	-0.1	0.1	2	5	1	0.30073	3.325205
Cu	1500	50	220	0.000667	170	170	1450	11.72	0.0078	0.30073	0.02599
Pb	10	0	30	0.1	30	30	10	300	30	0.30073	99.75615
Zn	15000	5000	33	6.67E-05	-4967	4967	10000	49.67	0.0033	0.30073	0.011011
				0.300733					31.011	0.30073	103.1184

Table 4. Calculation of the HPI for rainwater sample
(Source: [30])

Rain 1	**PPb (μg/L)**	**BIS /WHO STD**	**μg/l= mg/l*1000**								
Heavy Metal	**STD PERM LIMIT (Si)**	**Ideal Value (Ii)**	**Montd Value (Mi)**	**UNIT WT (Wi)**	**Mi-Ii**	**{Mi-Ii}**	**Si-Ii**	**Qi={Mi-Ii}/(Si-Ii) *100**	**WiQi**	**∑Wi**	**HPI**
Cd	5	3	1.9	0.2	-1.1	1.1	2	55	11	0.30073	36.577
Cu	1500	50	210	0.000667	160	160	1450	11.034	0.0074	0.30073	0.0245
Pb	10	0	1140	0.1	1140	1140	10	1140	1140	0.30073	3790.73
Zn	15000	5000	21	6.67E-05	-4976	4979	10000	49.79	0.0033	0.30073	0.01104
				∑0.30073					1151.01	0.30073	3827.35

Table 5. Ecological risk pre-industrial background
(Source: [31])

Parameter	**Cd**	**Cu**	**Pb**	**Zn**
Pre-industrial background values (Martin & Meybeck, 1979) (C_R^i)	0.2	32	20	129
Toxic Response Factor (T_f^i)	30	5	5	1

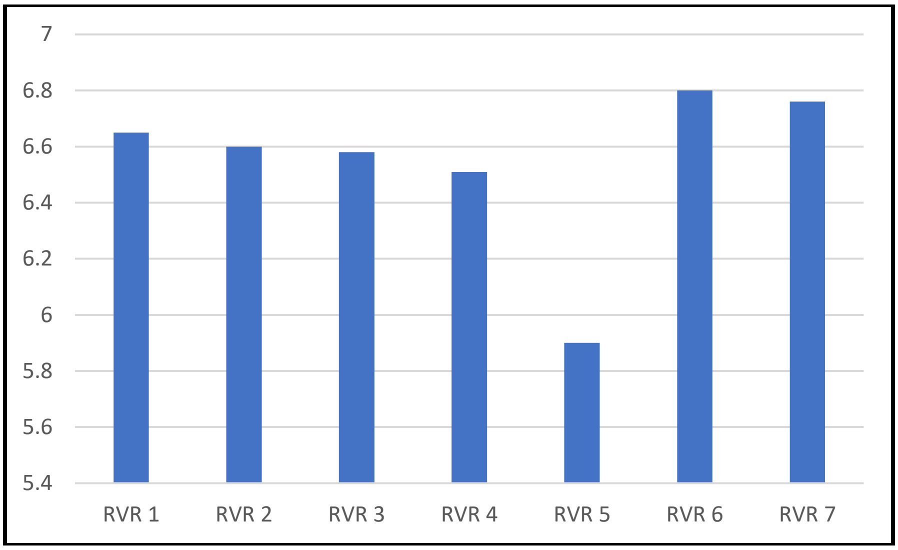

Fig. 4a. pH of river water samples

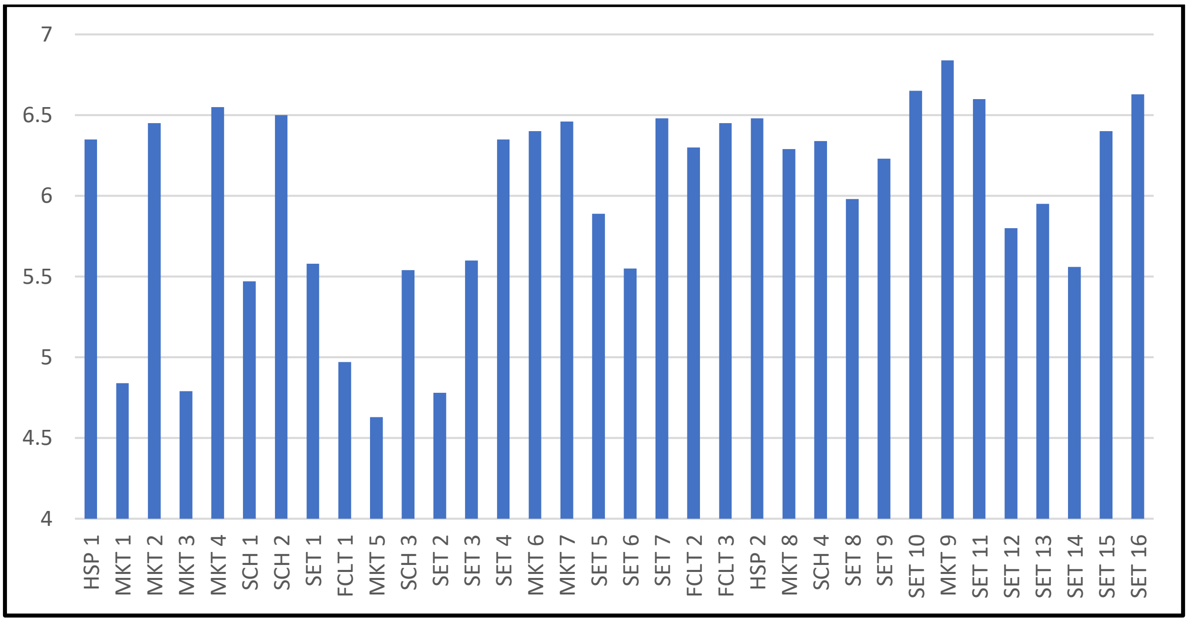

Fig. 4b. pH of Rainwater Samples

3.1.3 Turbidity

Turbidity, a crucial parameter in process control, serves as an indicator of potential issues in treatment processes, particularly coagulation, sedimentation, and filtration. It can lead to undesired taste and odors, impacting the photosynthesis process for algal growth. In this study, turbidity values for river water samples fell within the range of 15.69 to 42.54 NTU (Fig. 6a)

Rainwater samples exhibited varied turbidity values across different axes: Obigbo (3.0 to 38.21 NTU), Komkom-Obiama (1.71 to 6.96 NTU), Okoloma (2.0 to 16.10 NTU), Egberu (4.21 to 21.28 NTU), and Umu Agbai-Obete (4.27 to 20.00 NTU) (Fig. 6b).

For the turbidity, it was observed that the all the values of the river water samples were above the acceptable 15 NTU limits of the WHO standard [32], as well as majority of the rainwater samples were above its acceptable limits. However, only a few of the rainwater samples within some of the sampling axes were within the acceptable limit of the WHO standard [32]. The variation observed for the river water samples could be attributed to the release of suspended particles because of some human activities like fishing and sand mining in the area and this is in line with the report of Nkwoji et al., [37] and the work of Ezekwe et al., [38] who recorded turbidity of 10 in pond water at Imo River Basin area sampled. The turbidity values of the precipitation water in the area show that approximately one-third meet the WHO standards [32], while a significant majority of over two-thirds exceed the prescribed limits.

3.1.4 Total Suspended Solids (TSS)

TSS, represents particles in water exceeding 2 microns, while particles smaller than 2 microns are considered total dissolved solids (TDS). Suspended solids encompass various particles like silt, clay, organic matter, plankton, and larger elements such as sand. Surface water bodies, influenced by factors like runoff, erosion, and human activities, can exhibit different levels of suspended solids [39]. Increased erosion from riverbanks and streams contributes to higher TSS levels in water, causing particles to settle and impart a murky appearance. Rainwater, initially relatively pure, can accumulate particles and pollutants as it falls through the atmosphere [40]. TSS values, often linked to water turbidity, were within the range of 27.12 to 36.89 Mg/l for river water samples (Fig. 7a). Rainwater samples exhibited varying TSS values across different axes: Obigbo (1.82 to 51.86 mg/L), Komkom-Obiama (2.00 to 38.15 mg/L), Okoloma (4.68 to 42.04 mg/L), Egberu (3.25 to 31.90 mg/L), and Umu Agbai-Obete (2.54 to 14.23 mg/L) (Fig. 7b).

The TSS values for river water and rainwater samples indicated that the area has higher values obtained at the river channel along the course of Imo River while lower values are spread at the southeastern part. When compared with the WHO standard [32], it was observed that all values for both river water and rainwater samples were within the acceptable limits. Surface water, including rivers, lakes, and oceans, can contain varying levels of suspended solids depending on factors such as runoff, erosion, and human activities [39]. While rainwater generally starts as relatively pure water, as it condenses from water vapor in the atmosphere. However, as rainwater falls through the atmosphere, it can pick up various particles and pollutants [40].

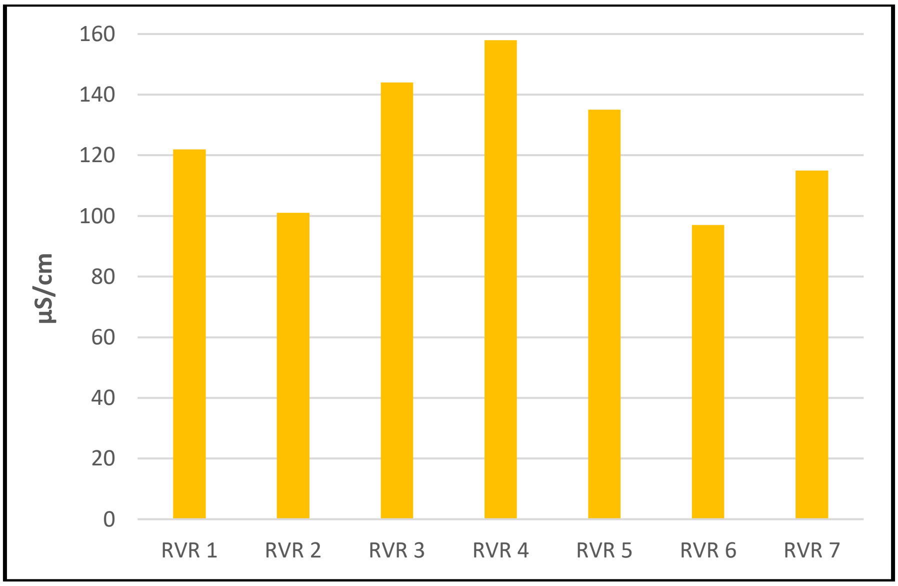

Fig. 5a. EC of river water samples

Table 6. Chemophysical parameters and heavy metals of the samples

	pH	EC (µS/cm)	Turbidity (NTU)	TSS (mg/L)	Cd (mg/L)	Cu (mg/L)	Pb (mg/L)	Zn (mg/L)
Rainwater								
Mean	5.991	32.878	10.860	18.381	<0.002	0.193	1.309	0.615
Max	6.84	102.45	38.21	51.86	<0.003	0.31	2.42	2.011
Min	4.63	5.75	1.71	1.82	<0.002	0.08	0.11	0.00
River Water								
Mean	6.543	124.571	27.443	30.52	<0.002	0.2017	0.189	0.328
Max	6.80	158.00	42.54	36.89	<0.003	0.43	1.04	1.21
Min	5.90	97.00	15.69	27.12	<0.002	0.06	0.01	0.02

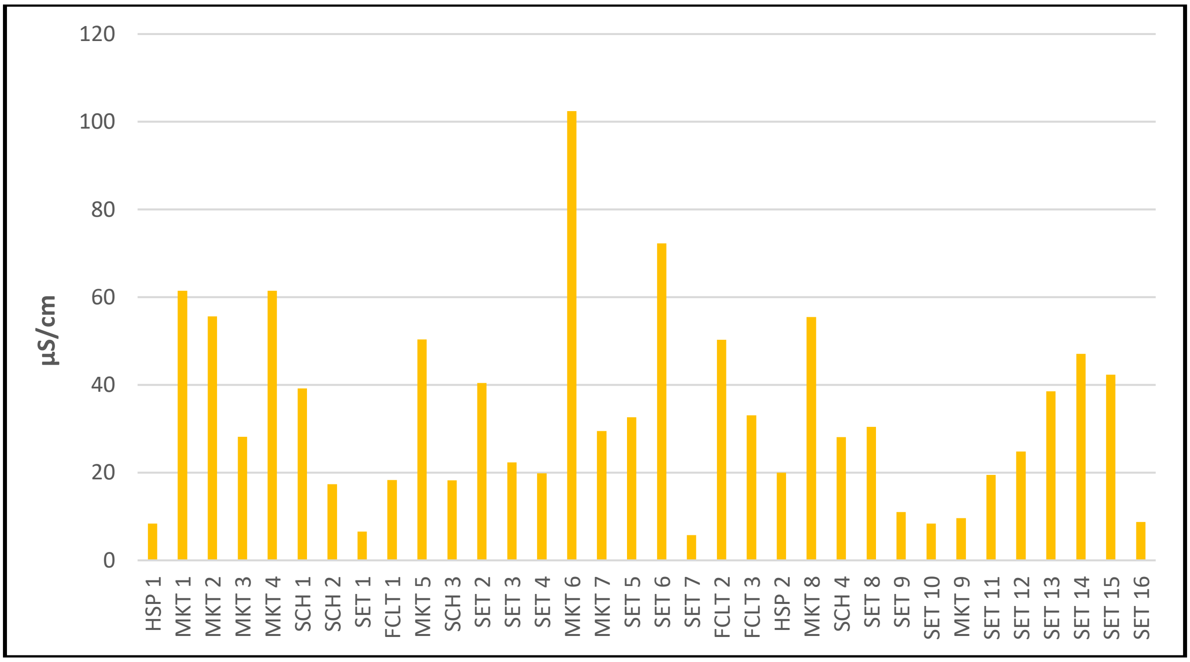

Fig. 5b. EC of Rainwater Samples

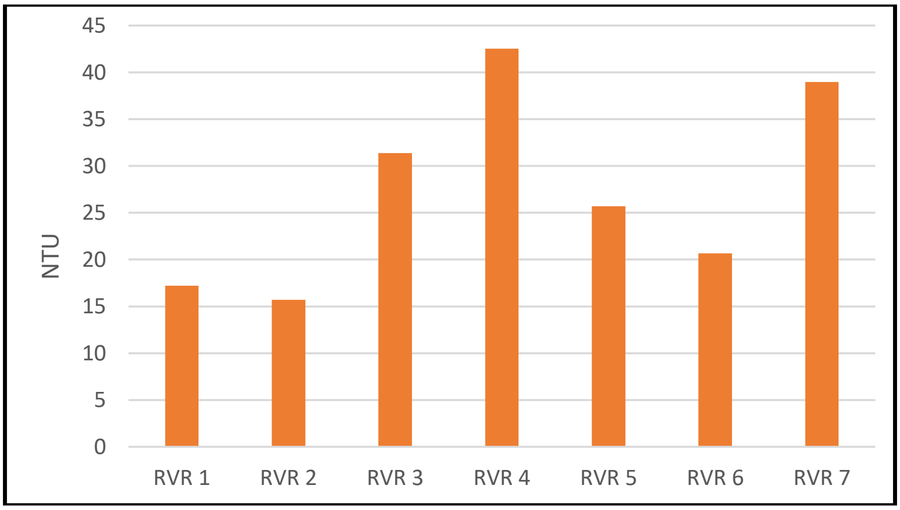

Fig. 6a. Turbidity of river water samples

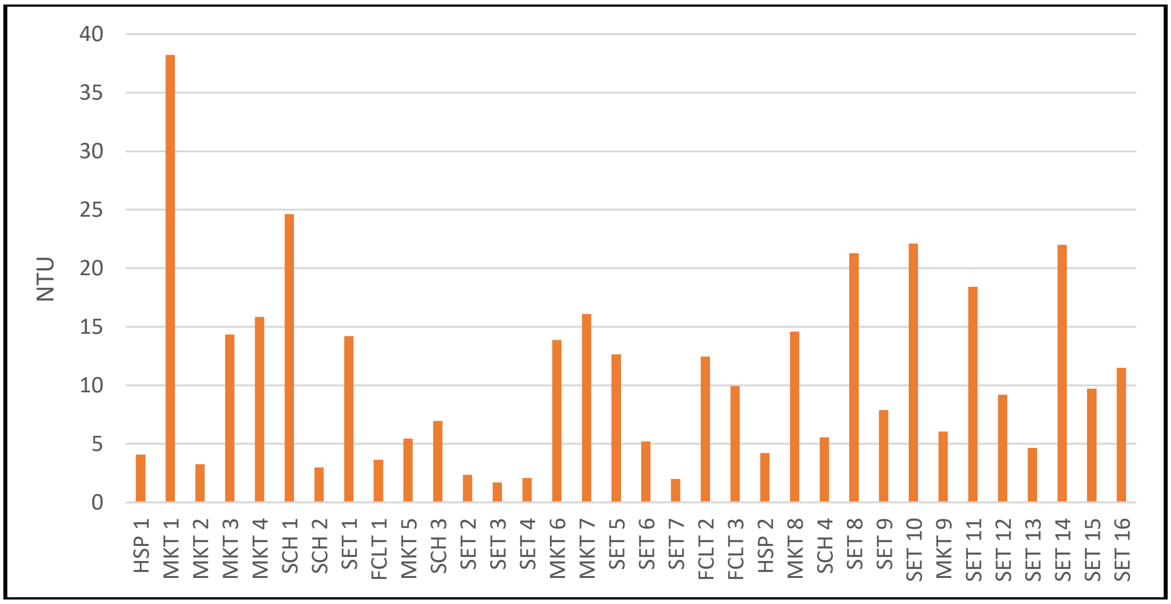

Fig. 6b. Turbidity of rainwater samples

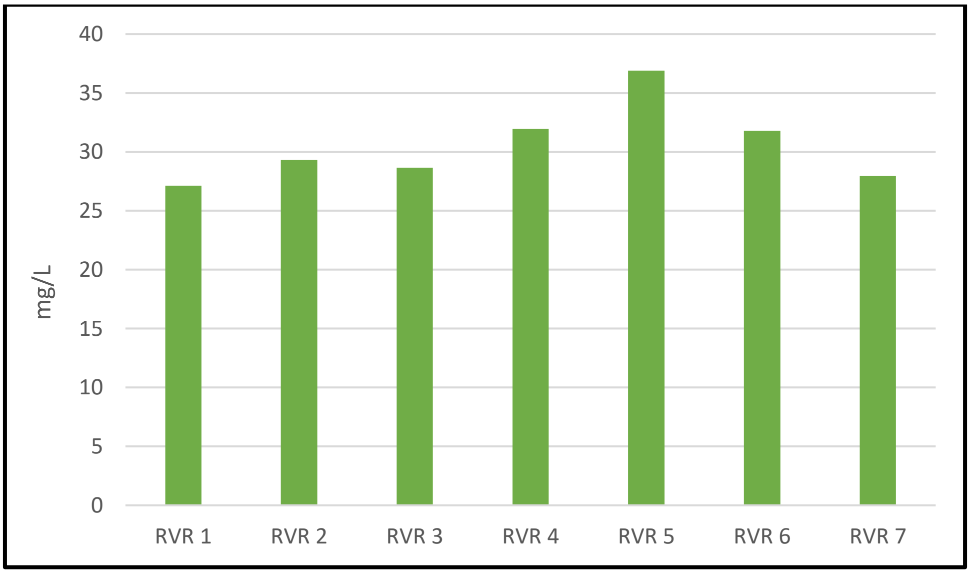

Fig. 7a. TSS of river water samples

3.2 Heavy Metals

The heavy metal analysis conducted in Oyigbo area, Rivers State, focused on the assessment of Cadmium (Cd), Copper (Cu), Lead (Pb), and Zinc (Zn). Cadmium, a naturally occurring metal present in rocks and soils, and can be transported to the water media (surface water, rainwater, and groundwater), can pose toxicity risks even at low concentrations, with potential health implications. Copper, an essential trace element in human tissues, plays a crucial role in various bodily functions; however, elevated concentrations may lead to adverse effects on the kidneys and liver [20]. Zinc, recognized as an immune booster, is generally beneficial in trace amounts; however, excessive consumption may result in nausea or vomiting. Lead (Pb), among the most toxic heavy metals, can contaminate water sources through various sources, causing severe health issues such as cancer and central nervous system damage.

The concentration values for river water samples at seven points were analyzed and presented in Fig. 8a. Cadmium values were consistently found to be <0.003 mg/L. Copper concentrations ranged from 0.08 to 0.43 mg/L, lead concentrations ranged from 0.01 to 1.04 mg/L, and zinc concentrations ranged from 0.02 to 1.21 mg/L. Notably, higher concentrations of Zn and Pb were observed at river water sample locations 4 and 5. It is important to highlight that the lead concentration in the river samples exceeded the drinking water standards set by both the World Health Organization (WHO) [32] and the Nigerian Standard for Drinking Water Quality (NSDWQ) [33]. These findings underscore the significance of continuous monitoring and effective measures to address heavy metal contamination in the water sources of the Oyigbo area.

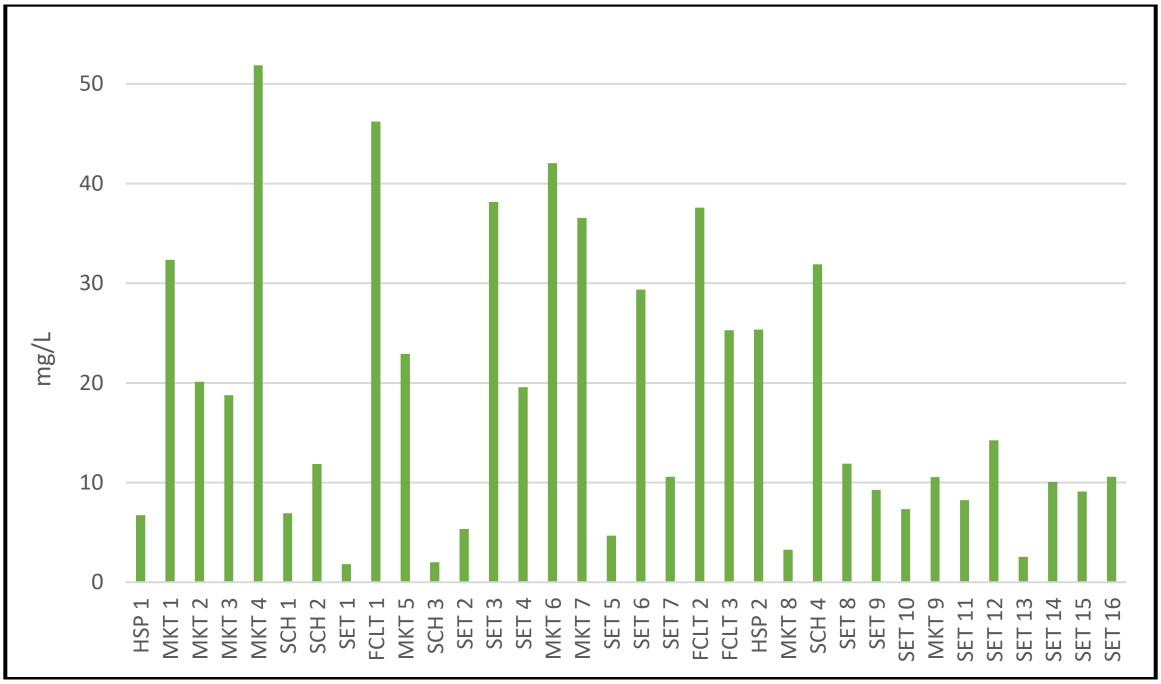

Fig. 7b. TSS of Rainwater Samples

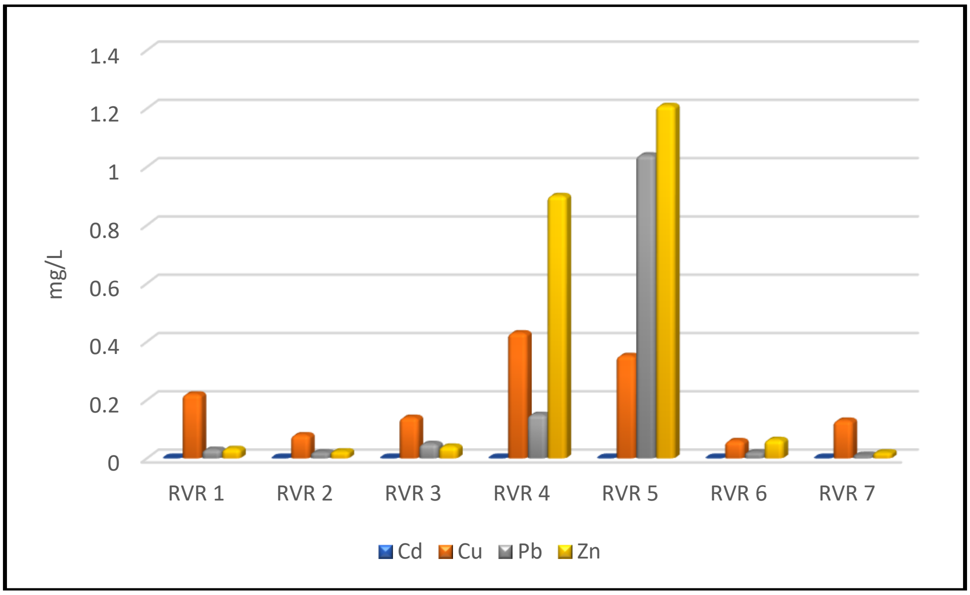

Fig. 8a. Heavy metals distribution for river water samples

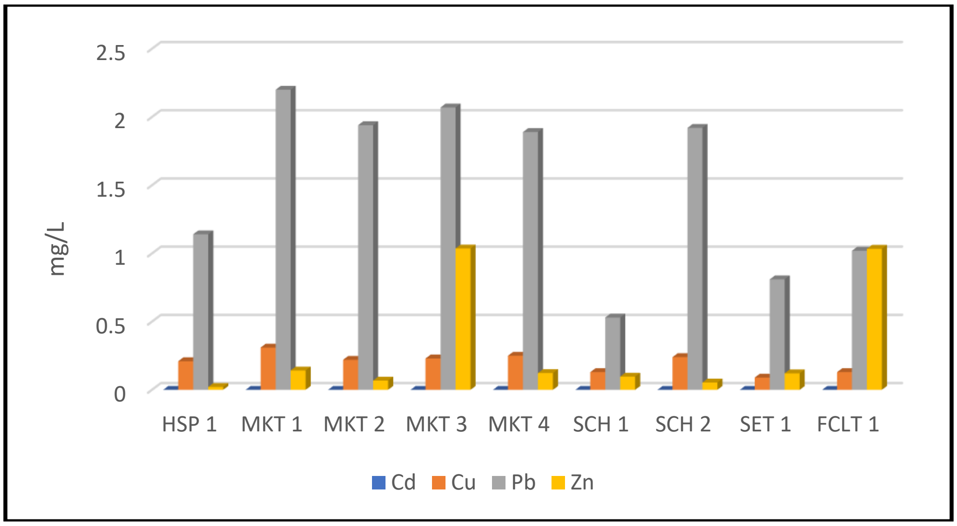

Fig. 8b. Heavy Metals Distribution of Rainwater Samples for Obigbo Axis

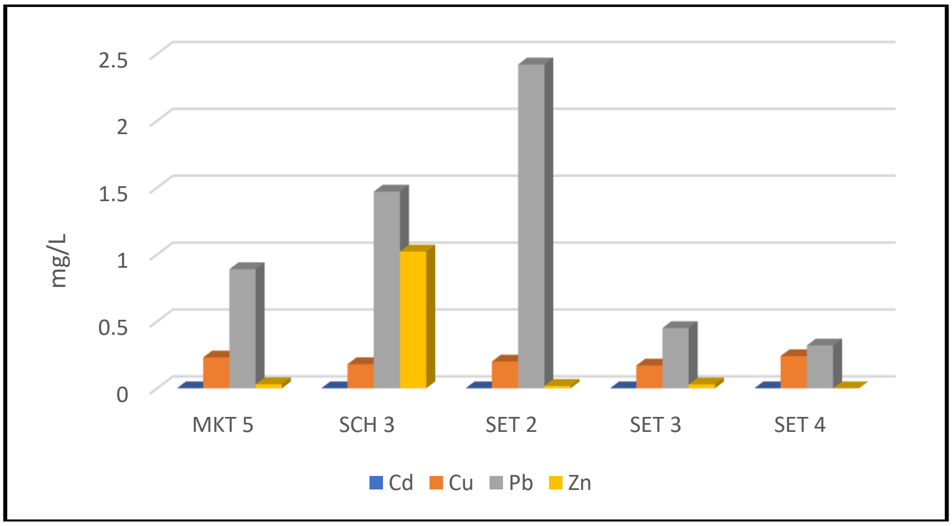

Fig. 8c. Heavy Metals Distribution of Rainwater Samples for Komkom-Obiama Axis

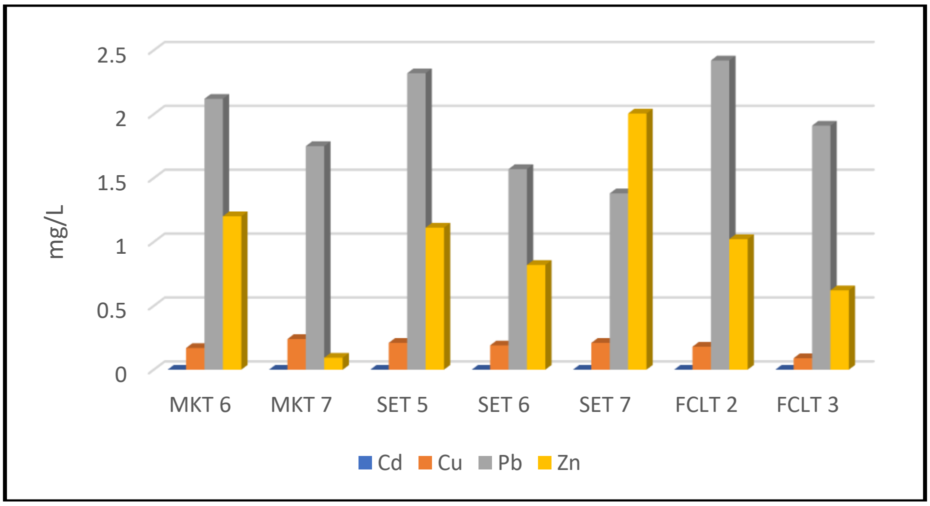

Fig. 8d. Heavy metals distribution of rainwater samples for Okoloma Axis

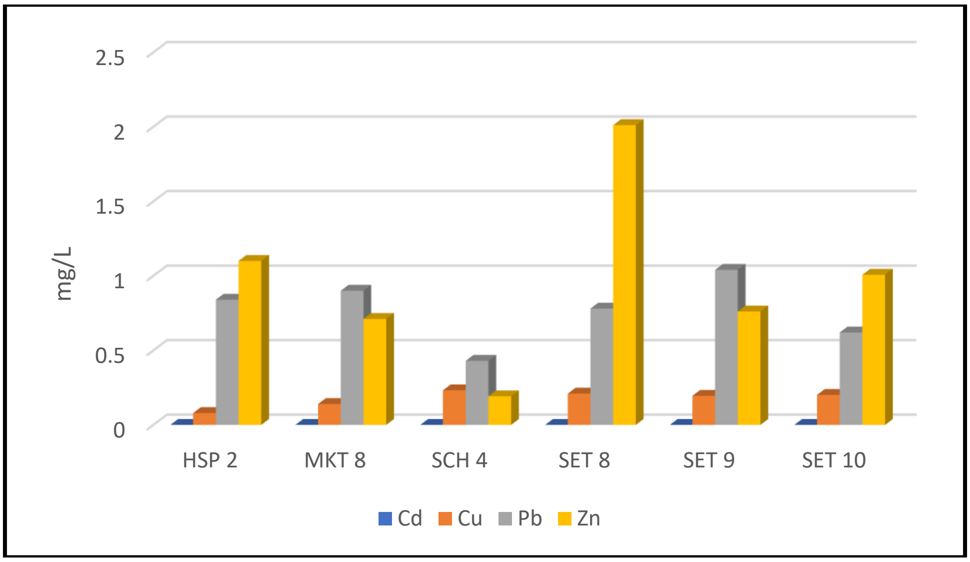

Fig. 8e. Heavy metals distribution of rainwater samples for Egberu Axis

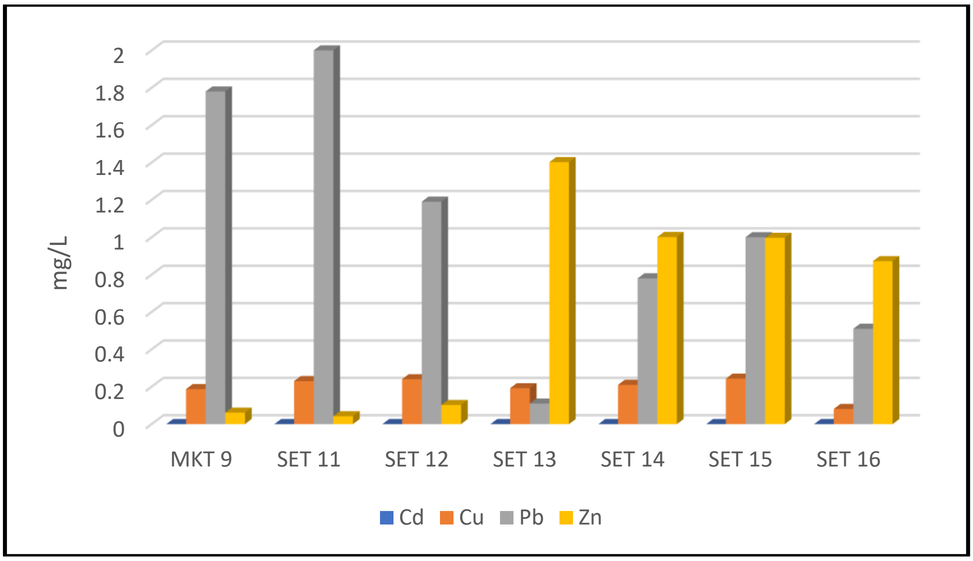

Fig. 8f. Heavy metals distribution of rainwater samples for Umu Agbai-Obete Axis

Regarding the rainwater samples (Fig. 8b, 8c, 8d, 8e, and 8f), the concentration values for cadmium ranged from <0.002 to <0.003 mg/L. Copper values varied between 0.09 to 0.31 mg/L, lead concentrations ranged from 0.9 to 2.42 mg/L, and zinc values ranged from 0 to 2.011 mg/L. While cadmium, copper, and zinc values fell within the acceptable limits of the World Health Organization (WHO) standard [32], lead concentrations exceeded the acceptable limit, indicating slight contamination. There is a higher concentration of Zn and Pb in the river water sample location 4 and 5. From the result, Pb is found to be above the WHO set standard for drinking water in the RVR 4, and RVR 5 samples. For the rainwater samples, Pb and Zn are also higher in concentration in all the sampled locations. However, while Zn is lower than the WHO set standard [32], Pb is recorded to be much above the standard for drinking.

3.3 Pollution Level Assessment

3.3.1 Heavy Metal Pollution Index (HPI) for River water

The calculation of the heavy metal pollution assessment and heavy metal pollution index for the seven (7) river water samples were carried out in Microsoft excel and reported using the format shown in (Table 7, and 8). The result shows that river samples RVR 1, RVR 3, RVR 4 and RVR 5 are above 100 which indicate pollution while RVR 2, RVR6 and RVR 7 that are below 100 are not polluted [17]. It is obvious that the highest contributor of the HPI value in all the sampled station is Pb and the least contributor to the HPI is Zn. The order of HPI values from the least to the highest is Zn < Cu < Cd < Pb. The highest values were obtained from the Okoloma and the Komkom-Obiama axis of the study area. This likely points to closeness to a source of heavy metal pollution in the area. From the map it is near the Afam power plant and Okoloma Gas plant industrial area.

3.3.2 Heavy Metal Pollution Index (HPI) for Rainwater

The HPI values for the thirty-four (34) rainwater samples collected to assess the quality for heavy metal contamination were calculated and the results were displayed below (Table 9, and 10). From Table 10, the result of the HPI shows that rainwater samples from all the sampled locations are above 100 which indicates pollution [17]. It is obvious that the highest contributor of the HPI value is Pb in all the sampled station and the least contributor to the HPI is Zn. The order of HPI values from the least to the highest is Zn < Cu < Cd < Pb. The range of HPI values for Cd are 3.325 to 36.577; HPI values for Cu range from 0.0045 to 0.0397; for Pb is from 365.77 to 8046.99; for Zn it ranges from 0.0066 to 0.0097 and for the Total HPI, the value ranges from 402.38 to 4396.54. Their average/mean values are Cd (27.780); Cu (0.0218); Pb (4345.86); Zn (0.0097).

3.4 Potential Ecological Risk Index (PERI)

3.4.1 Ecological risk index for river water

The calculation of the ecological risk index for the river water samples, and ecological risk index of the samples of the study area was carried out using Microsoft excel as contained in the table below (Table 11 and 12).

The ecological risk index values of the river samples shows that Cd, Cu, Pb and Zn have their EiR and RI values less than 40 and 30 respectively (EiR < RI (3.6134) < 40). The result shows that they fall in Group A of the ecological risk standard level according to Li et al., [19] (Table 13). This level shows that they fall in the slight risk pollution degree in the river water samples collected in Oyigbo area. This risk level corresponds to Hakanson [18] classification, which is low ecological risk, (i.e. when Er< 40). When Er values occur in the range of 40 and 80, it indicates moderate ecological risk. When the values occur between 80 and 160, it shows considerable ecological risk. When the values are between 160 and 320, it shows high ecological risk. When the values are above 320, it indicates serious ecological risk.

However, the Potential Ecological Risk (PERI) according to Li et al., [19] which was calculated as the sum of all risk factors for heavy metals in the environment revealed that when the values of PERI obtained are < 150, then it is classified as low ecological risk or slight risk level of Table 13 [19]. When the value obtained is between 150 and 300, then it falls to the moderate ecological risk level or medium level. When it is between 300 and 600, it falls in the high potential ecological risk or strong risk level. When the value obtained is more than 600 it shows significantly high potential ecological risk or very strong potential ecological risk.

3.4.2 Ecological risk index for rainwater

The calculation for ecological risk index, and the ecological risk index of rainwater samples of Oyigbo area is presented in Table 14, and 15. From the table, the RI value is 23.20145. This value is less than 40, hence EiR < RI (23.20145) < 40. It shows that the heavy metal parameters sampled (Cd, Cu, Pb, Zn) were found in Group A and from (Table 13), it is classified as having slight risk. All the rainwater samples are polluted with regards to HPI analysis.

The order of metallic ion concentration from HPI index include Zn < Cu < Cd < Pb for the river water samples and the order for the rainwater samples is Zn < Cu < Cd < Pb. The ecological risk index inferred an environment with low or slight risk of pollution. The ecological risk values (Er) for the metal samples for river and rainwater occur in the following order Cd > Cu > Pb > Zn, and Cd > Pb > Cu > Zn respectively. The relationship between the two indices showed that Zn was the least contributor to heavy metal contamination of Oyigbo.

Table 7. Calculation of HPI of river water samples

River 1	**PPb (µg/L)**	**BIS /WHO STD**	**µg/l= mg/l*1000**								
Heavy Metal	**STD Perm Limit (Si)**	**Ideal Value (Ii)**	**Montd Value (Mi)**	**Unit WT (Wi)**	**Mi-Ii**	**{Mi-Ii}**	**Si-Ii**	**Qi={Mi-Ii}/(Si-Ii) *100**	**WiQi**	**∑Wi**	**HPI**
Cd	5	3	2.9	0.2	-0.1	0.1	2	5	1	0.30073	3.325205
Cu	1500	50	220	0.000667	170	170	1450	11.72	0.0078	0.30073	0.02599
Pb	10	0	30	0.1	30	30	10	300	30	0.30073	99.75615
Zn	15000	5000	33	6.67E-05	-4967	4967	10000	49.67	0.0033	0.30073	0.011011
				0.300733					31.011	0.30073	103.1184

Table 8. HPI for river water samples

Sample Stations	Study Axis	HPI of each Parameters				Index
S/N		**Cd**	**Cu**	**Pb**	**Zn**	**∑HPI**
RVR 1	Obigbo	3.3252	0.0259	99.756	0.0110	103.118
RVR 2		3.3252	0.0046	66.504	0.0110	69.845
RVR 3		3.3252	0.0138	166.260	0.0109	169.610
RVR 4	K.Obiama	3.3252	0.0581	498.781	0.0091	502.173
RVR 5	Okoloma	3.3252	0.0461	3458.213	0.0157	3461.600
RVR 6	Umu Agbai-	3.3252	0.0015	66.504	0.0109	69.842
RVR 7	Obete	3.3252	0.0122	33.252	0.0110	36.601
MINIMUM		3.3252	0.0015	33.25	0.0091	36.601
MAXIMUM		3.3252	0.0581	3458.21	0.0157	3461.600
AVERAGE		3.3252	0.0232	627.04	0.01137	630.391
STD. DEV.		4.79E-16	0.0215	1258.53	0.00203	1258.54

The ecological risk index (Er) of heavy metal is the response to toxicity factor which classifies heavy metal toxicity levels according to ecological risk magnitude of Hakanson [18]. However, the potential ecological risk index (RI) evaluated the total risk caused by all the sampled metals in the study area. This index (RI) described the response the biological environment shows to any toxic metal and their potential ecological risk caused by the overall metals [20]. The ecological risk indices (Er) and Potential Ecological Risks (RI) showed that for all the metal ions that were sampled in the 41 stations (both River samples and Rainwater samples) of Oyigbo area, their Er and RI values were below 40 indicating slight risk level or low ecological risk as they all fall below the threshold value of 150 [19].

3.5 Environmental Quality Implications

The assessment outcomes reveal a subtle perspective on the intensity of precipitation and surface water contamination and the overall environmental quality in the Oyigbo study area. The pH levels indicate reasonable samples implying slightly acidic environments, which can lead to aluminum mobilization, nutrient limitations, and harm to aquatic life and well-being of all organisms relying on these environments [5]. Fig. 9a displays the relationship between the pH and turbidity of the rain and river water in comparison with the WHO standards [32].

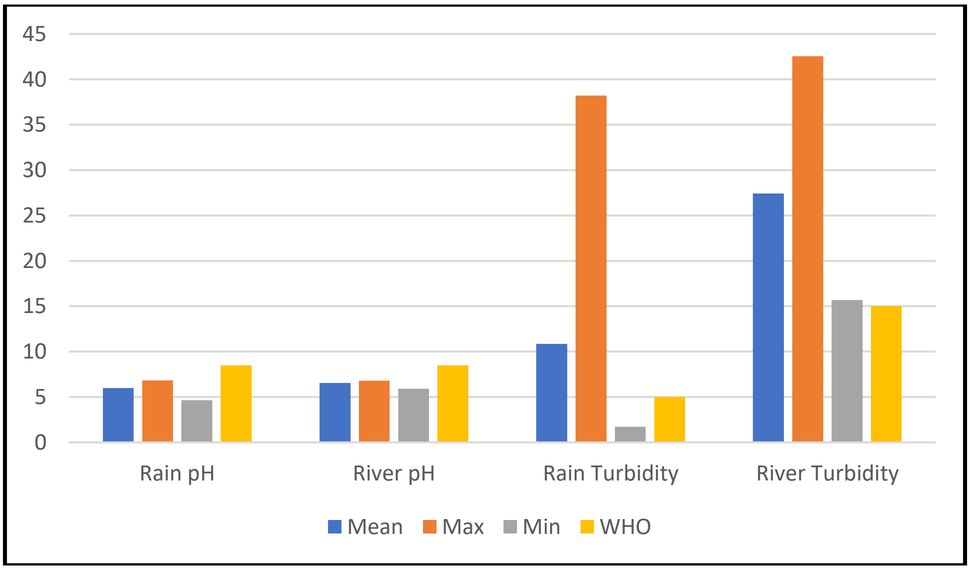

Fig. 9a. pH and Turbidity (NTU) Distribution of Water Samples in Comparison with WHO Standards

Table 9. Calculation of HPI for Rainwater Samples

Rain 1	**PPb (μg/L)**	**BIS /WHO STD**	**μg/l= mg/l*1000**								
Heavy Metal	**STD Perm Limit (Si)**	**Ideal Value (Ii)**	**Montd Value (Mi)**	**Unit WT (Wi)**	**Mi-Ii**	**{Mi-Ii}**	**Si-Ii**	**Qi={Mi-Ii}/(Si-Ii) *100**	**WiQi**	**∑Wi**	**HPI**
Cd	5	3	1.9	0.2	-1.1	1.1	2	55	11	0.30073	36.577
Cu	1500	50	210	0.000667	160	160	1450	11.034	0.0074	0.30073	0.0245
Pb	10	0	1140	0.1	1140	1140	10	1140	1140	0.30073	3790.73
Zn	15000	5000	21	6.67E-05	-4976	4979	10000	49.79	0.0033	0.30073	0.01104
				∑0.30073					1151.01	0.30073	3827.35

Table 10. HPI for Rainwater Samples

Sample Stations		Study Axis	HPI Values of Each Parameter				Index
S/N	**Codes**		**Cd**	**Cu**	**Pb**	**Zn**	**HPI**
1	HSP1	Obigbo	36.577	0.0245	3790.734	0.0110	3827.35
2	MKT1		36.577	0.0397	7315.45	0.0107	7352.08
3	MKT2		3.325	0.0260	6450.90	0.0109	6454.26
4	MKT3		36.577	0.0275	6883.17	0.0088	6919.79
5	MKT4		3.325	0.0306	6284.64	0.0108	6288.00
6	SCH1		3.325	0.0122	1762.36	0.0109	1765.71
7	SCH2		3.325	0.0290	6384.49	0.0109	6384.39
8	SET1		3.325	0.0061	2693.42	0.0108	2696.72
9	FCLT1		36.577	0.0122	3391.71	0.0088	3428.31
10	MKT5	Komkom Obiama	36.577	0.0275	2959.43	0.0110	2996.05
11	SCH3		36.577	0.0199	4888.05	0.0088	4924.66
12	SET2		36.577	0.0229	8046.99	0.0110	8083.61
13	SET3		36.577	0.0183	1496.34	0.0110	1532.95
14	SET4		36.577	0.0290	1064.07	0.0110	1100.68
15	MKT6	Okoloma	36.777	0.0183	7049.43	0.0084	7086.04
16	MKT7		36.577	0.0290	5819.11	0.0109	5855.73
17	SET5		3.325	0.0245	7714.48	0.0086	7717.83
18	SET6		3.325	0.0214	5220.57	0.0092	5223.93
19	SET7		36.577	0.0240	4588.78	0.0066	4625.39
20	FCLT2		36.577	0.0199	8046.99	0.0088	8083.60
21	FCLT3		36.577	0.0061	6351.14	0.0097	6387.73
22	HSP2	Egberu	36.577	0.0045	2793.17	0.0086	2829.76
23	MKT8		36.577	0.0138	2992.68	0.0095	3029.29
24	SCH4		36.577	0.0278	1429.84	0.0107	1466.45
25	SET8		3.325	0.0245	2593.65	0.0066	2597.02
26	SET9		36.577	0.0222	3458.21	0.0094	3494.82
27	SET10		3.325	0.0231	2061.63	0.0089	2064.98
28	MKT9	Umu Agbai-Obete	36.577	0.0209	5918.87	0.0109	5955.47
29	SET11		36.577	0.0275	6650.41	0.0109	6687.03
30	SET12		36.577	0.0290	3956.99	0.0109	3993.61
31	SET13		36.577	0.0217	365.773	0.0080	402.38
32	SET14		36.577	0.0245	2593.66	0.0089	2630.27
33	SET15		36.577	0.0295	3325.21	0.0089	3361.82
34	SET16		36.577	0.0047	1695.85	0.0092	1732.44
	Minimum		3.325	0.0045	365.77	0.0066	402.38
	Maximum		36.777	0.0397	8046.99	0.0110	8083.46
	Average		27.780	0.0218	4345.86	0.0097	4396.54
	STD Dev.		15.368	0.0082	2263.89	0.0013	2246.34

Table 11. Calculation of the ecological risk index for river water samples

RVR 1 Parameter	Bn Or C(I/R)	T(i/r)	C(i/D)	Ci/f	Ei/r	RI
Cadmium	0.2	30	0.0029	0.0145	0.435	0.477131
Copper	32	5	0.22	0.006875	0.034375	
Lead	20	5	0.03	0.0015	0.0075	
Zinc	129	1	0.033	0.000256	0.000256	
					0.477131	

Table 12. The ecological risk index for river water

S/N	Sample Station	Study Axis	Cd	Cu	Pb	Zn	RI
			$\boldsymbol{Ei_R} = T_R^i \times C_f^i$	$\boldsymbol{Ei_R} = T_R^i \times C_f^i$	$\boldsymbol{Ei_R} = T_R^i \times C_f^i$	$\boldsymbol{Ei_R} = T_R^i \times C_f^i$	$\sum \boldsymbol{Ei_R}$
1	RVR 1	Obigbo	0.435	0.03438	0.0075	0.000256	0.47713
2	RVR 2		0.435	0.01250	0.0050	0.000186	0.45269
3	RVR 3		0.435	0.02188	0.0125	0.000318	0.46969
4	RVR 4	K. Obiama	0.435	0.06719	0.0375	0.006984	0.54667
5	RVR 5	Okoloma	0.435	0.05500	0.2600	0.009380	0.75938
6	RVR 6	Umu-agbai	0.435	0.00938	0.0050	0.000496	0.44987
7	RVR 7	Obete	0.435	0.02031	0.0025	0.000155	0.45797
	$\sum$		0.87	0.005469	0.01	0.000411	3.6134

Table 13. Ecological risk levels
(Source: [19])

Er i	Pollution degree	RI	Risk degree	Risk level
Er i< 30	Slight	RI < 40	Slight	A
30 ≤ Er i<60	Medium	40 ≤ RI<80	Medium	B
60 ≤ Er I < 120	Strong	80 ≤ RI < 160	Strong	C
120 < Eri ≥ 240	Very strong	160 ≤ RI < 320	V. Strong	D
Eri ≥240	Extremely strong	RI ≥ 320		-

Table 14. Calculation of the ecological risk index for rainwater samples

Rain 1						
Parameter	**Bn Or C(I/R)**	**T(i/r)**	**C(i/D)**	**Ci/f**	**Ei/r**	**RI**
Cadmium	0.2	30	0.0019	0.0095	0.285	0.602975
Copper	32	5	0.21	0.006563	0.032813	
Lead	20	5	1.14	0.057	0.285	
Zinc	129	1	0.021	0.000163	0.000163	
					0.602975	

Table 15. The ecological risk index of rainwater

S/N	**Sample Station**	**Study Axis**	**Cd**	**Cu**	**Pb**	**Zn**	**RI**
			$Ei_R = T_R^i \times C_f^i$	$Ei_R = T_R^i \times C_f^i$	$Ei_R = T_R^i \times C_f^i$	$Ei_R = T_R^i \times C_f^i$	$\sum Ei_R$
1	HSP1	Obigbo	0.285	0.0328	0.285	0.00016	0.60298
2	MKT1		0.285	0.0480	0.550	0.00110	0.88454
3	MKT2		0.435	0.0344	0.485	0.00053	0.95490
4	MKT3		0.285	0.0359	0.518	0.00803	0.84647
5	MKT4		0.435	0.0391	0.473	0.00095	0.94752
6	SCH1		0.435	0.0203	0.133	0.00075	0.58856
7	SCH2		0.435	0.0375	0.480	0.00042	0.95292
8	SET1		0.285	0.0141	0.203	0.00094	0.50250
9	FCLT1		0.285	0.0203	0.255	0.00802	0.56833
10	MKT5	Komkom	0.285	0.0359	0.223	0.00023	0.54367
11	SCH3	Obiama	0.285	0.0281	0.368	0.00792	0.68855
12	SET2		0.285	0.0313	0.605	0.00014	0.92139
13	SET3		0.285	0.0265	0.113	0.00023	0.42429
14	SET4		0.285	0.0375	0.080	0.00000	0.40250
15	MKT6	Okoloma	0.285	0.0266	0.530	0.00931	0.85087
16	MKT7		0.285	0.0375	0.4375	0.00073	0.76073
17	SET5		0.435	0.0328	0.5800	0.00862	1.05643
18	SET6		0.435	0.0297	0.3925	0.00636	0.86354
19	SET7		0.285	0.0328	0.3450	0.01554	0.06784
20	FCLT2		0.285	0.0281	0.6050	0.00792	0.92605
21	FCLT3		0.285	0.0141	0.4775	0.00481	0.78138
22	HSP2	Egberu	0.285	0.0125	0.2100	0.00853	0.51603
23	MKT8		0.285	0.0219	0.2250	0.00551	0.53739
24	SCH4		0.285	0.0363	0.1075	0.00149	0.43024
25	SET8		0.435	0.0328	0.1950	0.01559	0.67840
26	SET9		0.285	0.0305	0.2600	0.00500	0.58137
27	SET10		0.435	0.0314	0.1550	0.00781	0.62921
28	MKT9	Umu Agbai	0.285	0.0292	0.4450	0.00047	0.75969
29	SET11	Obete	0.285	0.0359	0.5000	0.00033	0.82126
30	SET12		0.285	0.0375	0.2975	0.00079	0.62079
31	SET13		0.285	0.0300	0.0275	0.01087	0.35337

S/N	**Sample Station**	**Study Axis**	**Cd**	**Cu**	**Pb**	**Zn**	**RI**
			$Ei_R = T_R^i \times C_f^i$	$Ei_R = T_R^i \times C_f^i$	$Ei_R = T_R^i \times C_f^i$	$Ei_R = T_R^i \times C_f^i$	$\sum Ei_R$
32	SET14		0.285	0.0328	0.1950	0.00776	0.52057
33	SET15		0.285	0.0379	0.2500	0.00773	0.58070
34	SET16		0.285	0.0127	0.1275	0.00676	0.43192
							23.20145

Turbidity levels exceeding WHO standards in both river and rainwater samples imply poor water clarity and significant pollution or sedimentation, impacting light penetration, potentially reducing sunlight for photosynthesis, and compromising oxygen levels causing a possible disruption to the aquatic habitats and harming plant food source and health in the environment of the study area [41].

From Fig. 9b, the variation in Electrical Conductivity (EC) suggests spatial differences, with higher values along the Imo River course, indicating potential contaminated environment. The high EC across the study area with comparison to WHO standards implies elevated concentrations of dissolved pollutants serving as electrolytes, affecting osmoregulation and metabolism in aquatic organisms [15] and potentially influencing the environmental quality and health of the Oyigbo study area. Conversely, the lower Total Suspended Solids (TSS) within WHO limits indicates lesser larger solid materials in the water sources, which is good for the physical environmental quality and health.

From Fig. 9c, heavy metal concentrations, especially Lead (Pb) in river water samples, surpassing drinking water standards, underscore the intensity of contamination, necessitating immediate attention to prevent health risks. Rainwater samples, while generally acceptable, exhibit elevated Pb concentrations, signaling potential environmental concerns from adverse effects on human health, especially affecting the nervous system, cognitive development in children, and cardiovascular health [11]. The calculated Heavy Metals Pollution Index (HPI) categorizes the area's environment as polluted, with Pb identified as the primary contributor, emphasizing the urgency of targeted interventions. The Potential Ecological Risks Index (PERI) classifies the pollution risk as slight, indicating a low ecological risk level.

In general, this study chemically and physically characterizes the Oyigbo surface and precipitation water resources and classifies the area as a slightly polluted, low ecological risk, lead-contaminated environment. The environmental exposure to Pb contamination poses risks to aquatic life and potential bioaccumulation in the food chain of the Oyigbo area, warranting attention to prevent health risks and protect aquatic life and the broader ecosystem.

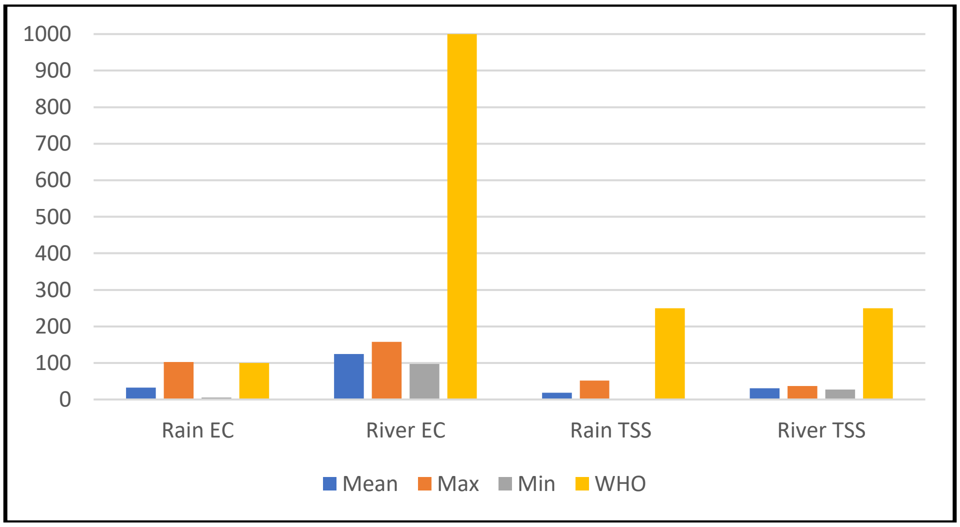

Fig. 9b. EC (μS/cm) and TSS (mg/L) distribution of water samples in comparison with WHO standards

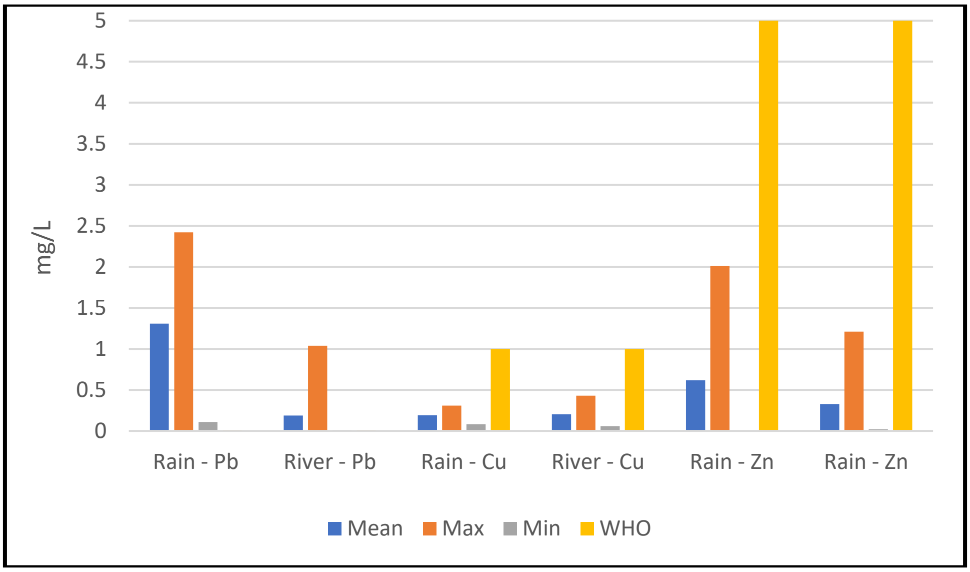

Fig. 9c. Heavy metals distribution of water samples in comparison with WHO standards

4. CONCLUSION

Petroleum industry operations in the Niger Delta, with the illegal oil mining activities features critical environmental and health impacts, particularly the introduction of significant pollutants such as soot into the atmosphere. The chemophysical and metallic characterization of surface water (river) and precipitation (rain) in the Oyigbo Local Government Area (LGA) of Rivers State, Nigeria, employing laboratory analysis of various chemical and physical parameters and heavy metals, provides a better understanding of the environmental dynamics. The assessment outcomes reveal subtle yet significant perspectives on the intensity of precipitation and surface water contamination, emphasizing the overall environmental quality in the Oyigbo study area. Despite a low Potential Ecological Risks Index, the findings emphasize the need for prompt interventions to address contamination and ensure the well-being of the environment and public health in Oyigbo.

ETHICAL APPROVAL

As per international standards or university standards written ethical approval has been collected and preserved by the author(s).

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Akudinobi BEB, Chibuzor SN. Hydrochemical evaluation of water sources in Warri metropolis, Delta State, Nigeria. Journal of Basic Physical Research. 2012; 3:64-72.
2. Samuel P, Elechi O, Julius NE. Total Hydrocarbon Contents: Spatial Variations in Aquatic Environment of Oyigbo Communities, Rivers State. International Journal of Environmental Protection and Policy. 2022;10(1):1-5.
3. Anornu GK, Kabo-bah AT, Anim-Gyampo M. Evaluation of groundwater vulnerability in the Densu River basin of Ghana. American Journal of Human Ecology. 2012;1(3):79-86.
4. Khatri N, Tyagi S. Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. Frontiers in life science. 2015; 8(1):23-39.
5. Anslem OA. Negative effects of gas flaring: the Nigerian experience. Journal of

Environment Pollution and Human Health. 2013;1(1):6-8.

6. Orji D, Ndu A, Ihesinachi K, Adaunwo EO. The total petroleum hydrocarbon contents of the ambient air within Port Harcourt and environs. Chemistry Research Journal. 2019;4(3):117-123.
7. Chen D, Guo Z. The Source, Transport, and Removal of Chemical Elements in Rainwater in China. Sustainability. 2022; 14(19):12439.
8. Singh RL, Singh PK. Global environmental problems. Principles and applications of environmental biotechnology for a sustainable future. 2017;13-41.
9. Fagorite VI, Ahiarakwem CA, Okeke OC, Onyekuru SO. Physico-chemical characteristics of otamiri river and its sediments in parts of Owerri. Elixir Geology. Elixir International Journal. 2019; 131:53223-53229.
10. Shammas NK, Wang LK, Wang MHS. Sources, chemistry and control of acid rain in the environment. In Handbook of Environment and Waste Management: Acid Rain and Greenhouse Gas Pollution Control. 2020;1-26.
11. Olowoyo DN. Physicochemical characteristics of rainwater quality of Warri axis of Delta state in western Niger Delta region of Nigeria. Journal of Environmental Chemistry and Ecotoxicology. 2011; 3(12):320-322.
12. Okorhi-Damisa FB, Ogunkeyede AO, Akpejeluh P, Okechukwu L. Analysis of soot in rainwaters around Warri metropolis. International Journal of Scientific Development and Research. 2020; 5(5):319-325.
13. Seiyaboh EI, Izah SC. Review of impact of anthropogenic activities in surface water resources in the Niger Delta region of Nigeria: a case of Bayelsa state. International journal of Ecotoxicology and Ecobiology. 2017;2(2):61-73.
14. Sánchez AS, Cohim E, Kalid RA. A review on physicochemical and microbiological contamination of roof-harvested rainwater in urban areas. Sustainability of Water Quality and Ecology. 2015;6:119-137.
15. Bhateria R, Jain D. Water quality assessment of lake water: a review. Sustainable Water Resources Management. 2016;2:161-173.
16. Omokpariola DO, Nduka JK, Kelle HI, Mgbemena NM, Iduseri EO. Chemometrics, health risk assessment and probable sources of soluble total petroleum hydrocarbons in atmospheric rainwater, Rivers State, Nigeria. Scientific Reports. 2022;12:11829.
 Available:https://doi.org/10.1038/s41598-022-15677-7
17. Abou Zakhem B, Hafez R. Heavy metal pollution index for groundwater quality assessment in Damascus Oasis, Syria. Environmental earth sciences. 2015;73 (10):6591-6600.
18. Hakanson L. An ecological risk index for aquatic pollution control. A sedimentological approach. Water Res. 1980;14:975–1001.
19. Li RZ, Pan CR, Xu JJ, Ding GZ, Zou Y. Application of Potential Ecological Risk Assessment Model Based on Monte Carlo Simulation, Res. Environ. Sci. 2012; 25:1336–1343.
20. Liu C, Zhang J, Li F, Yang J, Qiu Z, Cai Y, Zhu L, Xiao M, Wu Z. Trace elements spatial distribution characteristics, risk assessment and potential source identification in surface water from Honghu Lake, China. Journal of Central South University. 2018;25(7):1598–1611.
 DOI:https://doi.org/10.1007/s11771-018-3852-2
21. NBS National Bureau of Statistics – Nigeria: Social Statistics Report; 2006.
22. Samuel P, Elechi O, Julius NE. Total Hydrocarbon Contents: Spatial Variations in Aquatic Environment of Oyigbo Communities, Rivers State. International Journal of Environmental Protection and Policy. 2022;10(1):1-5.
23. Adejuwon JO. Rainfall seasonality in the Niger delta belt, Nigeria. Journal of Geography and Regional Planning. 2012;5(2):51.
24. Okorafor GF, Okoronkwo C, Oladejo E. Infrastructure Development and Maintenance in the Oil Producing Areas of Southern Nigeria: Implications Options and Challenges. Fepnek Synergy Journal. 2017;30.
25. Okorie DO, Nwosu PO. Seasona Variations in Physico-Chemical of Imo River. Journal of Pharmacy and Biological Sciences. 2014;9(5):07-09.
26. Omoko EN, Opara AI, Onyekuru SO, Ibeneme SI, Akakuru OC, Fagorite VI. Pollution status and hydrogeochemical characterization of water resources in Onne industrial layout and environs, Rivers

state, Nigeria. Sustainable Water Resources Management. 2023;9(4):116.

27. Short KC, Stäuble AJ. Outline of geology of Niger Delta. AAPG bulletin. 1967; 51(5):761-779.
28. Doust H, Omatsola E. Niger-Delta. In: Edwards, J.D. and Santogrossi, P.A., Eds., Divergent/Passive Margin Basins, AAPG Memoir 48, American Association of Petroleum Geologists, Tulsa. 1990;239-248.
29. Reijers TJA. Stratigraphy and Sedimentology of the Niger Delta. Geologos. 2011;17:133-162. Available:https://doi.org/10.2478/v10118-011-0008-3
30. Mohan SV, Nithila P, Reddy SJ. Estimation of Heavy Metal in Drinking Water and Development of Heavy Metal Pollution Index. Journal of Environmental Science and Health. 1996;A-31: 283-289. Available:https://doi.org/10.1080/10934529609376357
31. Martin JM, Meybeck M. Elemental Mass Balance of Materials Carried by Major World Rivers, Marine Chemistry. 1979; 7(3):173-206. DOI:10.1016/0304-4203(79)90039-2
32. World Health Organization (WHO) Guidelines for drinking-water quality. In: Incorporating 1st Addendum, 4th ed. World Health Organization, Geneva; 2017.
33. Nigerian Standard for Drinking Water Quality (NSDWQ) Nigerian Industrial Standard NIS 554, Standard Organization of Nigeria'; 2015. Available:https://africacheck.org/wp-content/uploads/2018/06/Nigerian-Standard-for-Drinking-Water-Quality-NIS-554-2015.pdf
34. Olawale SA. Physico chemical analysis of water from Asa River, Ilorin, Nigeria. Imperial Journal of Interdisciplinary Research. 2016;2(3):122-129.
35. Pal KB, Pant RR, Rimal B, Mishra AD. Comparative assessment of water quality in the Bagmati River basin, Nepal. ZOO-Journal. 2019;5:68-78.
36. Bhardwaj K, Boora N, HAU H. Water Quality Parameter. Shweta Sharma. 2023;78.
37. Nkwoji JA, Yakub A, Ajani GE, Balogun KJ, Renner KO, Igbo JK, Ariyo AA, Bello BO. Seasonal variations in the water chemistry and benthic macroinvertebrates of a southwestern Lagoon, Lagos, Nigeria. Journal of American Science. 2010; 6(3):85-92.
38. Ezekwe IC, Ezekwe AS, China GN. Metal loading and alkaline mine drainage from active and A badoned mines in the Imo River Basin Area of South Eastern Nigeria. Journal of Water and Environmental Science. 2013;32:97–107.
39. Seiyaboh EI, Izah SC. Review of impact of anthropogenic activities in surface water resources in the Niger Delta region of Nigeria: a case of Bayelsa state. International journal of Ecotoxicology and Ecobiology. 2017;2(2):61-73.
40. Sánchez AS, Cohim E, Kalid RA. A review on physicochemical and microbiological contamination of roof-harvested rainwater in urban areas. Sustainability of Water Quality and Ecology. 2015;6:119-137.
41. Seiyaboh EI, Izah SC. Review of impact of anthropogenic activities in surface water resources in the Niger Delta region of Nigeria: a case of Bayelsa state. International journal of Ecotoxicology and Ecobiology. 2017;2(2):61-73.

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