Contents list available http://www.kinnaird.edu.pk/

Journal of Natural and Applied Sciences Pakistan

Journal homepage: http://jnasp.kinnaird.edu.pk/

PHYSICO-CHEMICAL PROPERTIES AND HEAVY METALS CONTENT OF WATER FROM EDUMANON MANGROVE FOREST, BAYELSA STATE, NIGERIA

Abdulganiyu Mohammed Galadima[1*], Ibrahim Abubakar[2], Shehu Ibrahim[3]
[1]Department of Biotechnology, School of Biological Sciences, Federal University of Technology, Owerri, Imo, Nigeria
[2]Department of Biology-Chemistry, Idris Koko Technical College, Farfaru, Sokoto, Nigeria
[3]Department of Chemistry, Shehu Shagari University of Education, Sokoto, Nigeria

Article Info

*Corresponding Author
Email: amgaladima001@gmail.com

Abstract

Mangrove forests are specific environments that serve many social, cultural, educational, and economic benefits. Water is important for survival, growth, and reproduction of human, plants, and animals. This study aims at evaluating the physico-chemical properties, heavy metals and PAHs contents of water from Edumanon mangrove forest of Nembe local government areas of Bayelsa state, Nigeria. The physical and chemical properties of the water sample were determined using standard methods of APHA, ASTM, and AOAC. Heavy metals and PAHs contents of the water sample were determined using AAS and HPLC analysis, respectively. The temperature, pH, turbidity, conductivity, salinity, TH, TSS, TDS, DO, BOD, and COD level in the water sample was 29°C, 7.5, 39.96NTU, 1765.24µS/cm, 1543.22mg/L, 1272.07mg/L, 41.41mg/L, 14564.45mg/L, 11.32mg/L, 25.78mg/L, and 69.66mg/L, respectively. The level of chloride, total alkalinity, bicarbonate, sulphates, nitrate, and phosphate in the water sample 178.96mg/L, 125.17mg/L, 96.44mg/L, 63.24mg/L, 17.93mg/L, and 11.36mg/L, respectively. The water sample demonstrated a 1.11 mg/L, 1.04 mg/L, 1.65 mg/L, 0.92 mg/L, 1.21 mg/L, and 0.76 mg/L level of Cr, Cd, Pb, Ni, Co, and As, respectively. The amount of anthracene, acenapthene, napthalene, phenathrene, pyrene, and fluorine in the water sample was 20.86mg/ml, 24.33mg/ml, 18.03mg/ml, 19.71mg/ml, 12.12mg/ml, and 15.53mg/ml, respectively. The levels of physical and chemical parameters, heavy metals, and PAHs in the water sample were above the recommended values by WHO, FEPA, NSDWQ, SON, and/or NESREA for the survival of aquatic organisms and domestic uses.

Keywords

Heavy Metals, Edumanon, Mangrove forest, PAHs, Water

1. Introduction

Mangrove forests are the main productive environments in the world. Mangroves are woody trees and shrubs that grow in specific intertidal environments and cover about 60–70 % of the earth's tropical and subtropical coastal areas (Sohaib *et al.*, 2023). Mangroves occupy about 137,760 km worldwide comprising approximately 27,552 km (20 %) in Africa (Sohaib *et al.*, 2023). They are specific coastal environments that thrive in the warm, wet conditions of the tropics and subtropics (Saoum and Sarkar, 2024). Mangrove forests are nursery grounds for commercially and recreationally valued species, landing point for migratory birds, filtration of sediment, nutrients and pollutants, enhancement of coastal fisheries, and protects coastlines against natural disasters such as floods, waves and extreme weather conditions (Islam *et al.*, 2019). Other benefits of mangrove forests include erosion control and carbon sequestration (Saoum and Sarkar, 2024). Mangroves forests have the potential to sequester about 22.8 million metric tons of carbon each year (Sohaib *et al.*, 2023). Water is the most abundant substance on the Earth covers 71% of the Earth's mainly occupied surface water including rivers, mangroves, oceans, and other water bodies (Babalola *et al.*, 2024). Water is important for survival, growth, and reproduction of human, plants, and animals. Water is a habitat for aquatic organisms and important body for transportation, agricultural and industrial activities. Ground and surface water have been specifically used for consumption, domestic, and/or industrial uses. Surface water quality is a critical aspect of environmental health and sustainability (Syeed *et al.*, 2023). Quality water is essential for meeting basic human needs, supporting health, livelihoods and economic development, underpinning food and energy security, and defending environmental integrity. Consumption of quality and safe water provides many significant health benefits to human, animals and aquatic organisms. Water pollution remains a global concern and major public health problem especially in low and middle income countries. About 1.7 billion people rely on drinking contaminated water worldwide (UNICEF/WHO, 2023). In low and middle income countries, most of the people lack accessibility to potable water supply thus, relies on surface water including mangroves, rivers, reservoir, springs, streams and groundwater as their primary sources of water. Environmental pollutions including water pollution from petroleum hydrocarbons have been causing environmental destructions including mangrove forest, water, soil, air, and biota (Onwuka *et al.*, 2021; Adegbite *et al.*, 2020). Water pollution causes changes in physical, chemical, and biological properties of water bodies to the extent that water is not potable for consumption and domestic uses. Physical and chemical properties of water affect the functions and structure of mangrove forests and have been threatened by human and industrial activities including oil exploration and exploitation (Agraz-Hernández *et al.*, 2020; Kamboj and Kamboj, 2019). The major causes of surface water pollution are crude oil spills, solid wastes, gaseous emissions, untreated industrial effluents, improper home waste disposal, and agricultural runoff (Uddin and Jeong, 2021; Akhtar *et al.*, 2021; Hasan *et al.*, 2019). Crude oil exploration and production activities caused water pollution by generating different pollutants including hydrocarbon components, heavy metals, polycyclic aromatic hydrocarbons (PAHs), and many other toxic substances into different water bodies (Azuamaha *et al.*, 2023; Gwary *et al.*, 2019). Consumption of water contaminated with chemical substances can causes serious adverse health effects. Consumption of polluted or contaminated water has been causing water-borne diseases such as cholera, typhoid fever, and dysentery (Khayan *et al.*, 2019). Report showed that about 190 million diseases are associated with consumption of contaminated water (Azuamaha *et al.*, 2023) and polluted water has caused about 2.2 million deaths worldwide (WHO, 2015). In developing countries including Nigeria, about 80% of diseases and more than 3.1% of deaths are associated with consumption of contaminated water (Azuamaha *et al.*, 2023; Adesakin *et al.*, 2020). Nigeria is one of the top oil-rich countries in the world and has beautiful landmarks as mangrove forest. Niger Delta is the largest wetland in Africa and one of the largest wetlands in the world. Niger Delta region of Nigeria consisted of nine states including Bayelsa state. The region has vegetation that covers landmass of 7.5 million ha and consists of extensive mangrove forests, brackish swamp forests, and rainforests (Zhang *et al.*, 2019). Many years ago activities of oil exploration and production have been taken placed in Niger Delta region. Niger Delta region is one of the fifth most severely petroleum-polluted environments in the world (Azuamaha *et al.*, 2023). It has been reported that about 0.7 – 1.7 million tons of crude oil spilled into water bodies including mangrove water, oceans, and rivers, and agricultural soils each year in Niger Delta region (Ekemube *et al.*, 2022). The activities of oil industries in Niger Delta have been causing serious environmental pollution and hazards on human, animals, plants, aquatic organisms and their habitats. The oil activities in the region have significantly cause destruction of mangrove forests, water bodies and groundwater sources (Gwary *et al.*, 2019). This is the reason why environmental pollution from crude oil exploration and exploitation has received much attention in the region. The aim of this study is to evaluate the physico-chemical properties, heavy metals and PAHs contents of water from Edumanon mangrove forest of Nembe local government area of Bayelsa state, Nigeria.

2. Materials and Methods

2.1 Chemicals and Reagents

All the chemicals and reagents used in this study were of analytical grade. The chemicals and reagents manufactured by Reidel-de Haem (Merck, Germany), Sigma-Aldrich (St. Louis, MO, USA), and BDH Chemical Limited Poole (England, UK) were purchased used in this study.

2.2 Study Area

This study was conducted in Nembe local government area, Bayelsa East, Bayelsa State, Nigeria. The Nembe communities are rich with mangrove forest named Edumanon Forest Reserve. Edumanon Forest Reserve is one of the largest mangrove forests in Niger Delta region covers part of Nembe with an estimated of about 9,324 hectares (Erefitei, 2016). Many activities including oil and gas installations, hunting practices, and intensive agricultural practices have been taken placed in the area. The communities in the area have been polluted by the oil industrial activities occurring in the area.

2.3 Collection of Mangrove Water Sample

The water sample was collected from the Edumanon Mangrove Forest, Nembe local government areas, Bayelsa State, Nigeria. The water sample was collected in washed and dried bottles from the surface to a depth of about 20 cm. To ensure a total distribution of contaminants the water sample was homogenized and transported to the laboratory for analyses.

2.4 Analysis of Physical Properties of the Water

2.4.1 Determination of Colour and Odour

The colour and odour of the water sample were determined by the physical observation and smelling organ, respectively.

2.4.2 Determination of Temperature

Temperature of the water sample was measured in-situ by standard method of APHA (2001) using a mercury-in-glass bulb thermometer. The thermometer was subsequently placed into the water sample and kept there until the mercury column reached a stable position. The readings were taken three times at five-minute intervals, and the average temperature value was calculated.

2.4.3 Determination of pH

The pH of water sample was determined using digital pH meter calibrated with buffer solution of pH 4.0 and 7.0 at temperature of 25 ^{0}C as described by APHA (2001). Two hundred miles of the water sample were measured into a beaker. The pH meter probe was inserted making sure it did not touch the beaker and the pH reading was then taken. In between readings, the electrode of the pH meter was rinsed with distilled water to avoid contamination.

2.4.4 Determination of Electrical Conductivity

The conductivity meter calibrated with potassium chloride solution was used to measure electrical conductivity of the water sample by using the method of APHA (2001). The water sample (200 mL) was measured into a sterile beaker. The calibrated conductivity meter was inserted into the beaker with the tip containing the electrode touching the water for approximately 3 minutes until the conductivity reading became stable. The meter readings were taken and recorded immediately. Between each reading the electrode of the conductivity meter was rinsed with distilled water, dried with tissue and then a portion of the sample.

2.4.5 Determination of Salinity

Titrimetric method was employed for the determination of salinity of the water sample as described by Mohammed et al. (2024). The water sample (1 mL) was transferred into a 20 mL volumetric flask and made up to the mark with distilled water. The flask was treated with 1 mL of potassium dichromate indicator and then shaked gently. The solution was titrated using silver nitrate solution until a brick red colour was observed. The titration was performed three times and the water salinity was obtained using the following equation:

$$\text{Salinity (mg/L)} = \frac{\text{A X N 58.5 X 1000}}{\text{Volume of Sample (mL)}}$$

Where;

A = Volume of silver nitrate; N = Molarity of silver nitrate

2.4.6 Determination of Total Hardness

Total hardness of the water sample was determined by the titration technique using the method of APHA (2001) with some modifications. The water sample (25 mL) was diluted with 50 mL of distilled water in an Erlenmeyer flask. One mile of buffer solution was added into the solution. The solution was titrated using 0.01M EDTA and 0.1M NaOH solutions and Erichrome Black T as indicator. The ethylenediamine tetra-acetic acid (EDTA) solution and few drops of Erichrome Black T were added to the diluted water sample. The solution was titrated against the 0.1M NaOH (5 mL) until a wine red colour was observed. The titration was continued by addition of 1 ml of the titrant with continuous shaking until the wine red colour changed to blue. The total hardness was calculated using following formula:

$$\text{Total hardness (mg/L)} = \frac{\text{Molarity}}{\text{Volume of Sample (mL)}} \text{ X } 1000$$

2.4.7 Determination of Total Suspended Solids

Gravimetric technique was used in determination of total suspended solids of the water sample using the method of AOAC (2000) and Mohammed et al. (2024). The water sample (100 mL) was passed through the glass fibre filter apparatus. The residue was dried in an oven at 103 ^{0}C to 105 ^{0}C for 1 day. The weight of the residue was measured using analytical weighing balance. The amount of total suspended solids was obtained using the following equation:

$$\text{Total suspended solids (mg/L)} = \frac{\text{Weight of dried residue (mg)}}{\text{Volume of sample filtered (mL)}} \text{ X } 1000$$

2.4.8 Determination of Total Dissolved Solids

The total dissolved solids content of the water sample was determined using gravimetric method as described by AOAC (2000) and Mohammed et al. (2024). One hundred miles of the water sample in pre-weighed evaporating dish was dried in an oven at temperature of 103 to 105^{o}C for 24 hour. The dish was transferred into desiccators, allowed to cool at room temperature and then weighed. The total dissolved solids content was obtained using the equation below:

$$\text{Total dissolved solids (mg/L)} = \frac{\text{W2} - \text{W1 (mg)}}{\text{Volume (mL)}} \text{ X } 1000$$

Where;

W_1= weight of the empty dish, W_2= weight of the empty dish + dry residue

2.4.9 Determination of Dissolved Oxygen

Dissolved oxygen (DO) level in the water sample was determined using the Winkler's method as described by APHA (2001). The water sample (250 mL) in glass reagent bottle was fixed in the field using Winkler's A (manganous sulphate solution) and Winkler's B (alkali-iodide) reagents and then brought to the laboratory for further processing. Conc. Sulphuric acid was added to free the fixed oxygen in the water sample and then titrated with sodium thiosulphate solution. The level of dissolved oxygen was calculated using the equation below:

Dissolved Oxygen = V_1 x 0.2 x 1000 ml / V

Where;

V_1= Volume of thiosulphate; V= Volume of sample taken

2.4.10 Biochemical Oxygen Demand

Dilution technique was employed in the determination of biological oxygen demand of the water sample using standard method (5-Day BOD Test) as described by Mohammed et al. (2024). The principle of the method involves an estimation of amount of oxygen consumed during a fixed period of 5 days which is related to the amount of organic matter present in the original sample. Two hundred miles of the water sample was filled by overflowing in airtight bottle of the specified size. Initially, the dissolved oxygen of the water sample was measured using the Schott Gerate Dissolved Oxygen meter. The water sample was then incubated at 20^{0}C for 5 days. Final dissolved oxygen of the water sample was then measured after the 5 days period. The BDO was obtained using the following equation:

BOD_5 (mg/L) = $[DO_1 - DO_0]/B$

Where;

DO_0 = Initial dissolved oxygen (immediately after preparation); DO_1 = Final dissolved oxygen (after 5 days of incubation); B = Volume of sample used.

2.4.11 Determination of Chemical Oxygen Demand

Colorimetric method was used to evaluate the chemical oxygen demand (COD) in the water sample as described by ASTM (2011) and APHA (2005). The method depends on the oxidation of organic and oxidizable inorganic substances present in water by mixture of standard potassium dichromate acid solution (APHA, 2005). The COD vial adapter was inserted in the cell holder of the spectrophotometer and the reagent blank was used to zero spectrophotometer. The vial containing the water sample was placed in the adapter. The COD was determined by observing the increase in green color of the reduced chromium (Cr^{3+}) or the decrease in yellow color of the dichromate ($Cr_2O_7^{2-}$). The COD value was measured three times and the average value was calculated.

2.5 Analysis of Chemical Properties of the Water

2.5.1 Determination of Total Alkalinity

Determination of the total alkalinity of the water sample was carried out using titration method as described by Mohammed et al. (2024). The principle of the method involves the reaction of carbonates and sodium hydroxide to form bicarbonate which reacts with phenolphthalein indicator to produce a pinkish colour. Fifty miles of the water sample was transferred into 250 mL conical flask followed by addition of two drops of 0.5 % w/v phenolphthalein indicator and then thoroughly mixed. The solution was initially titrated (T_1) against 0.05M H_2SO_4 until a pink colour was observed. Two drops of 0.5 %w/v methyl orange indicator were added to the pinkish solution and then thoroughly mixed. Finally, the solution was titrated (T_2) with 0.05M H_2SO_4 until a pale red colour was observed. The experiment was performed three times and the titre mean value was calculated. The total alkalinity was obtained using the following equation:

$$\text{Total alkalinity (mg/L)} = \frac{\text{Molarity (T1+T2)}}{\text{Volume of Sample(mL)}} \text{ X } 1000$$

2.5.2 Determination of Bicarbonate

The level of bicarbonate in the water sample was estimated by titration technique using the method of APHA (2005). The water sample was titrated with standardized HCl solution using methyl orange as indicator. At pH below 4.0, the methyl orange turns to yellow and the carbonic acid decomposes to give carbon dioxide and water. The titration was carried out in triplicate and the mean value was obtained.

2.5.3 Determination of Chloride

Chloride concentration in the water sample was analyzed by the titrimetric method as described by Babalola et al. (2024) with certain modifications. The water sample (100 mL) was pipetted into the conical flask followed by the addition of 1 ml of K_2CrO_4 indicator. For the blank, 100 mL of distilled water was transferred into a conical flask followed by addition of 1 mL of K_2CrO_4 indicator and 0.2 mL of 0.01M AgNO3 solution. The mixture was shaked gently and leaved to stand at room temperature. The sample solution was titrated with 0.2 mL of 0.02M AgNO3 solution to the colour of the comparison blank. The level of chloride was obtained using the following formula:

Chloride concentration= $(V_a - V_b)$ x M x 35.5 x 1000 / V

Where; V_a = Volume of silver nitrate used for titrating sample V_b = Volume of silver nitrate used for titrating blank = = 0.2 mL, V=Volume of sample taken, M = Molarity of AgNO3

2.5.4 Determination of Phosphate

The phosphate concentration in the water sample was determined by a colorimetric assay as described by ASTM (2004) and Mohammed et al. (2024). The method is based on the formation of yellow colour by the action of phosphates on molybdate ion under strong acidic conditions. The intensity of colour is directly proportional to the level of phosphate in the sample. Fifty miles of the water sample was added into the flask which was treated with ascorbic acid (20 mL) solution. The standard solution in another flask was also treated with 20 mL of ascorbic acid solution. The contents were allowed to stand at room temperature for five minutes and the absorbance was read at 650 nm wavelength. The level of phosphate was obtained from the standard curve constructed.

2.5.5 Determination of Nitrate

Nitrate was determined using colorimetric method as described by Baird et al. (2017). The calibration standards of the range 0.1 to l.0 mg/L were prepared by diluting appropriate volume to 50 mL. One sachet of the Nitraver 5 powder pillow was added to 10 mL of each standard into different volumetric flasks. The solution was thoroughly shaken, allowed to stand for 5 minutes after which amber colour developed. The absorbance of the sample against the blank was measured using spectrophotometer at 540 nm wavelength. The standard curve was constructed by plotting the absorbance against standard concentrations. The nitrate concentration in the water sample was obtained from the standard curve.

2.5.6 Determination of Sulphate

Sulphate concentration in the water sample was determined by spectrophotometeric method as described by Ramkumar et al. (2013) and Abali et al. (2023). The sulphate stock standard solution (l000 mg/L) was prepared by dissolving 1.479 g of anhydrous Na_2SO_4 in 500 mL of distilled water in 1000 mL volumetric flask which was then filled up with distilled water. From the stock solution, lower concentrations of 2.00, 4.00, 6.00, 8.00 and 10.00 mg/L were prepared in 100 mL volumetric flask by serial dilution method. Each standard solution (70 mL) was measured into 100 mL volumetric flask followed by the addition of 10 mL of Alcohol-Glycerol mixture and 5 g of finely divided BaCh crystal and then the volume was filled to mark. The contents were mixed thoroughly and allowed to stand. The absorbance of the sample against the blank was measured using spectrophotometer at 420 nm wavelength. The standard curve was constructed by plotting the absorbance against standard concentrations. The concentration of sulphate in the water sample was obtained from the standard curve.

2.6 Determination of Heavy Metals

The concentration of chromium, cadmium, lead, nickel, cobalt, and arsenic in the water sample was determined by atomic absorption spectrophotometeric (AAS) technique using the method of AOAC (1990; 2005).

2.7 Determination of Polyaromatic Hydrocarbons

The concentration of certain polyaromatic hydrocarbons **(**PAHs) in the water sample was determined by high-performance liquid chromatography (HPLC) technique using the method of EPA (1984) and Firmin et al. (2016). The analysis was performed using analytical column of 250 mm length and 4.6 mm i.d., packed with totally porus spherical RP-18 particle of size 5 um. The mobile phase used was a mixture of acetonitrile – water (70:30) at a flow rate of 1.0 mL per minute. The PAHs were detected using UV detector at a wavelength 254 nm for absorption. The data were processed with a CR7A chromatopac data processor. A standard solution of individual PAHs of different concentrations (5 to 50 mg) was dissolved in HPLC grade acetonitrile. The retention data were determined from the linearity of the detector using the standard solution. The concentrations of PAHs in the sample extract were expressed in mg/mL of the extract.

3. Results

3.1 Physical Properties of the Water Sample

Table 1 shows the physical properties of the crude oil contaminated water sample. The mangrove water sample is dark yellowish on colour with a repugnant, pleasant and gasoline-like odour. The temperature, pH, turbidity, conductivity, salinity, total hardness (TH), total suspended solids (TSS), total dissolved solid (TDS), dissolved oxygen (DO), biological oxygen demand (BOD), and chemical oxygen demand (COD) mean value of the water sample obtained in this study was 29 °C, 7.5, 39.96 NTU, 1765.24 μS/cm, 1543.22 mg/L, 1272.07 mg/L, 41.41 mg/L, 14564.45 mg/L, 11.32 mg/L, 25.78 mg/L, and 69.66 mg/L, respectively (Table 1).

Table 1: Physical Properties of the Water Sample

PARAMETER	VALUES
Colour/Appearance	Dark yellowish
pH	7.50 ± 0.07
Temperature (°C)	29.00 ± 0.06
Turbidity (NTU)	39.96 ± 0.10
Conductivity (μS/cm)	1765.24 ± 0.13
Salinity (mg/L)	1543.22 ± 0.02
Total Hardness (mg/L)	1272.07 ± 0.14
Total Suspended Solids (mg/L)	41.41 ± 0.02
Total Dissolved Solids (mg/L)	14564.45 ± 0.34
Dissolved Oxygen (mg/L)	11.32 ± 0.01
Biological Oxygen Demand (mg/L)	25.78 ± 0.12
Chemical Oxygen Demand (mg/L)	69.66 ± 0.88

Values are mean ± SEM (n = 3)

3.2 Chemical Properties of the Water Sample

The concentration of chemical parameters in the crude oil contaminated water sample is shown in Table 2. The mangrove water sample demonstrated a significant ($p < 0.05$) level of chloride (178.96 mg/L), total alkalinity (125.17 mg/L), bicarbonate (96.44 mg/L), sulphates (63.24 mg/L), nitrate (17.93 mg/L) and phosphate (11.36 mg/L) (Table 2).

However, the concentration of chloride was significantly ($p < 0.05$) higher compared to the other parameters. In comparison with the other parameters, the mangrove water sample exhibited a significant ($p < 0.05$) lower level of phosphate (Table 2).

Table 2: Chemical Properties of the Water Sample

PARAMETER	CONCENRATION (mg/L)
Total alkalinity	125.17 ± 0.001
Bicarbonate	96.44 ± 0.276
Chloride	178.96 ± 0.008
Sulphate	63.24 ± 0.001
Phosphate	11.36 ± 0.002
Nitrate	17.93 ± 0.183

Data are expressed as mean ± SEM (n = 3)

3.3 Heavy Metals Content of the Water Sample

Figure 1 shows the heavy metals level in the crude oil contaminated water sample. A significant ($p < 0.05$) level of chromium (1.11 mg/L), cadmium (1.04 mg/L), lead (1.65 mg/L), nickel (0.92 mg/L), cobalt (1.21 mg/L), and arsenic (0.76 mg/L) was observed in the water sample (Figure 4.3). However, the concentration of lead, cobalt, chromium and cadmium was significantly ($p < 0.05$) higher compared to the nickel and arsenic (Figure 1).

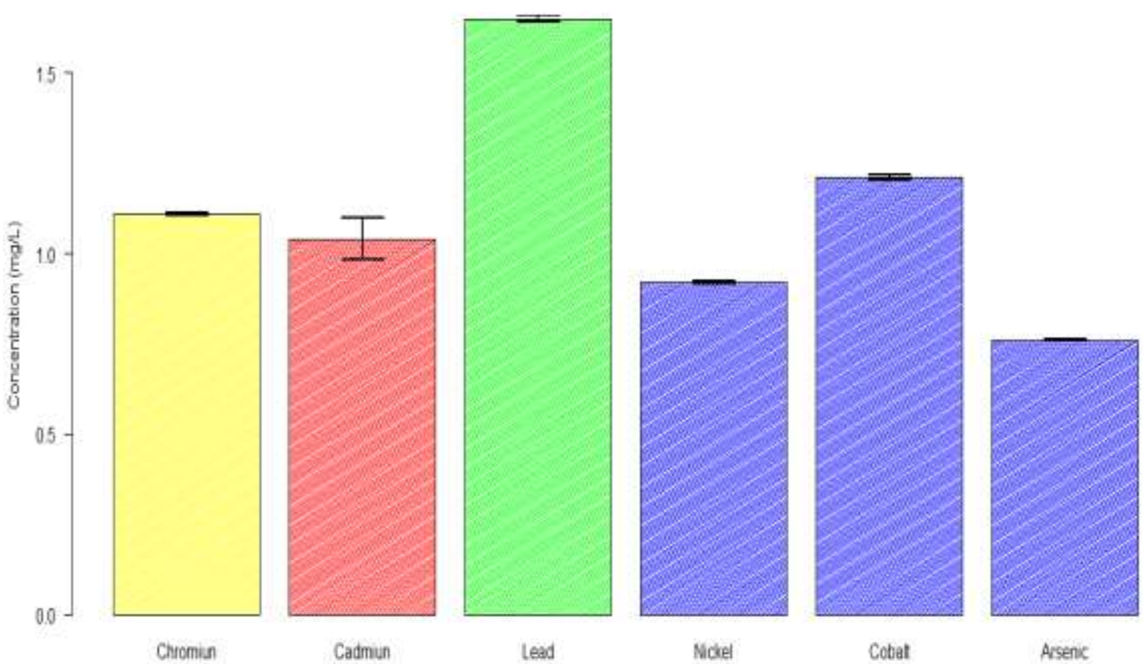

Figure 1: Heavy Metals Content of the Water Sample Data are mean ± SEM (n = 3)

3.4 PAHs Levels of the Water Sample

The level of some polyaromatic hydrocarbons (PAHs) in the crude oil polluted water sample is shown in Figure 2. The results showed that the water sample demonstrated a significant ($p < 0.05$) amount of anthracene (20.86 mg/ml), acenapthene (24.33 mg/ml), napthalene (18.03 mg/ml), phenathrene (19.71 mg/ml), pyrene (12.12 mg/ml), and fluorine (15.53 mg/ml) (Figure 2).

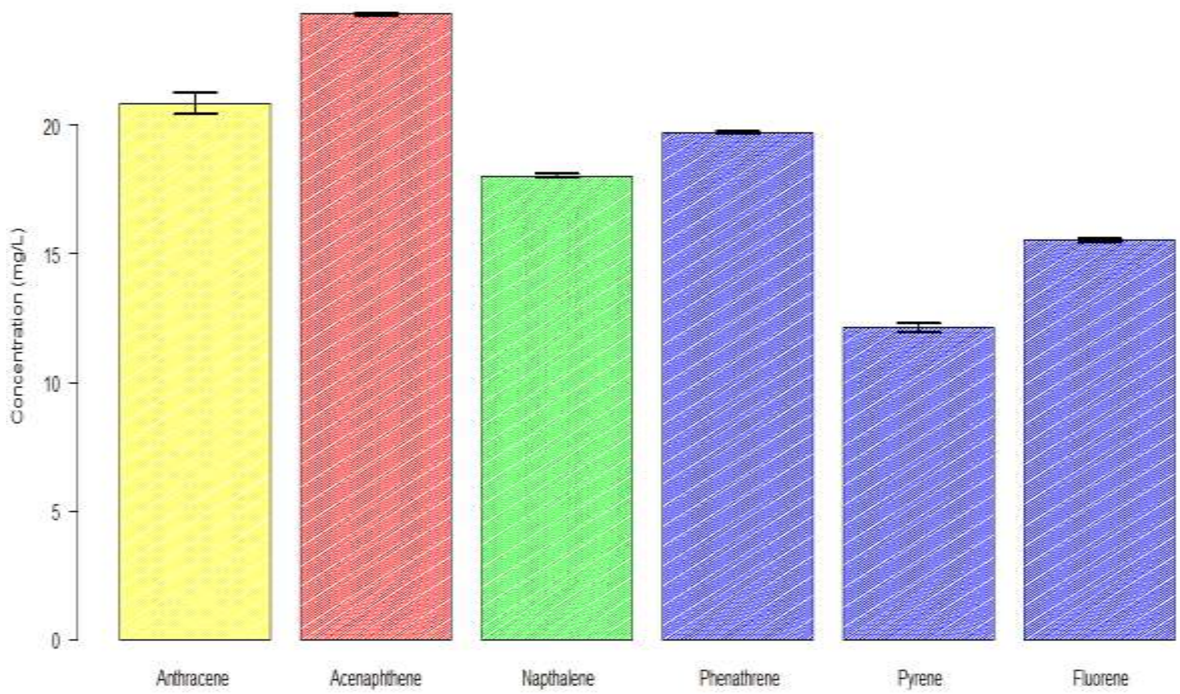

Figure 2: Concentrations of PAHs in the Water Sample

Values are expressed as mean ± SEM (n = 3). Polyaromatic hydrocarbons (PAHs)

4. Discussion

In this study, the pH value of the water sample is within the WHO (2011) recommended values 6.5 to 8.5. Asante et al. (2020) reported alteration in pH values in water which could be attributed to certain factors including mineral dissolution. The result of this study is in agreement with the findings reported by Owokotomo et al. (2020). Iyama and Edori (2014) reported a high pH value in the brackish water environment in the Niger Delta area. pH is a measure of acidity or alkalinity of water. The pH level of aquatic environments is determined to evaluate the water purity for domestic, agricultural, and industrial uses (Nsude and Orie, 2022; Owhoeke *et al.*, 2023). Changes in pH value of aquatic environments are mostly caused by presence of contaminants, pollutants and/or agents from industrial activities including oil industries activities (Dorleku, 2013). Water temperature is an important factor for controlling aquatic life (Carr and Neary, 2006). Elevated value of water temperature increases the metabolic activities of aquatic organisms (Murdoch *et al.,* 2001). In this study, the temperature ofthe water sample was within the recommended limit (22–32 ºC) set by SON (2007). Results of the relevant study showed that the temperature of water ranged from 23.3°C to 30.8°C (Barmon *et al.,* 2018). High temperature of water can be caused by the discharge of pollutants in the water bodies (Ezzat *et al.*, 2012; Boyle and Fraleigh, 2003). Electrical conductivity refers to determination of the ability of water or aqueous solution to transmit electricity. Electrical conductivity of water or solution is depending on the mobility rate of a number of current carrying substances present in water, environmental temperature, nature and type of ions present in water (Sharma and Walia, 2017). In the current study, the water sample demonstrated a high electrical conductivity above the recommended value (< 1000 µs/cm) by the World Health Organisation (2011) and the National Environmental Standard Enforcement Agency (2009), respectively. The high value of electrical conductivity indicated that the water sample contains a notable concentration of ionizable compounds or trace metal ions. High value of electrical conductivity and total dissolved solids (TDS) in water bodies is an indicator of potential mineral leaching or presence of solids wastes in water (Rahman *et al.,* 2019). Electrical conductivity of water provides important information for determination of total hardness and alkalinity of water. Turbidity of water refers to the measure of cloudiness of water caused by the presence of suspended particles including organic and inorganic matters (WHO, 2017c). The quality of water is determined by its turbidity level. In the current study the water sample demonstrated high turbidity level (39.96 NTU) above the recommended value (below 25 NTU) (Rosli *et al.,* 2010) for domestic uses. Elevated levels of turbidity of waterare associated with presence of pollutants in the water bodies (Azuamaha *et al.,* 2023). High turbidity level in surface or ground water is associated with release of wastes from industries and from sand dredging (Iyama and Edori, 2013; Onyegeme-Okerenta *et al.,* 2016). It has been reported that elevated level of water turbidity was attributed to the exploration and refining activities of oil causing discharged of pollutants including organic compounds and suspended particles in water bodies (Gad *et al.,* 2022). The presence of suspended particles including crude oil components in the mangrove water could be responsible for the high turbidity of the water observed in this study. Results of the present study showed that the water sample demonstrated a high total hardness value above the WHO recommended value (300 mg/L) for drinking water (WHO, 2020; SON, 2007). Hardness of water is determined by the presence of dissolved calcium and magnesium salts which are sources of water pollution mainly from industrial discharges (Tesfaye *et al.*, 2019; Onojake and Abrakasa, 2012). Changes in total hardness of water may be due to decomposition and mineralization of organic matters (Sekhar, 2020). Water salinity refers to the amounts of salt present in water bodies. Increase in water salinity increases the water density resulting to the water stratification (Edori *et al.,* 2020). High salinity of water affects certain biotic processes and can cause death of aquatic organisms if not control. Total suspended solids of water refer to the presence of organic particles and minerals in water bodies.

Results of this study indicated that the water sample demonstrated a high level of TSS more than the WHO recommended value (10 mg/L) for domestic reported that High level of water turbidity increases TSS level of water causing adverse health effects to aquatic life (Sri-Dattatreya *et al.,* 2018). In the present study TDS value of water sample is above the maximum limit values 600 mg/L and 500 mg/L set by WHO (2011), and SON (2007), respectively. The level of TDS in water is depends on the levels of organic and inorganic pollutants present in the water bodies (Rahmanian *et al.,* 2015). The TDS level in the water sample observed in the present study is higher than the values reported by the relevant study (Edori *et al.,* 2020) .The TDS value of water bodies is an important index for regulating biotic and abiotic factors in water bodies and for waste water treatment process (Thirupathaiah *et al.,* 2012). Elevated level of TDS in water change the composition of the water and can causes toxicity to aquatic organisms (Tawati *et al.,* 2018). Study showed that crude oil pollutants from oil activities, wastewater, municipal and agricultural run-off, and industrial effluents are responsible for TDS in water bodies (Okabekwa *et al.,* 2024). The elevated level of TDS observed in the water sample could be attributed to the presence of oil components in the mangrove water.Dissolved oxygen (DO) refers to the amount of oxygen that can be hold by water. It is depends on the temperature, salinity and pressure of water (APEC, 2011). Amount of dissolved oxygen is an indicator of prevailing water quality, trophic status and the tendency of water bodies to support survival of aquatic organisms (Sri-Dattatreya *et al.,* 2018). In this study the level of DO in the water sample is above the recommended value (6 mg/L) for the survival of aquatic organisms and domestic uses (WHO 2017a; 2017b). Low level of dissolved oxygen in water significantly affected the health of aquatic organisms (Shehu, 2019). Respiration and metabolic activities of aquatic organisms is determined by the level of Dissolved oxygen in water bodies (Nasrabadi *et al.,* 2016). Studies showed that crude oil components inhibit dissolution of atmospheric oxygen into water bodies reducing their freshness and quality (Azuamaha *et al.*, 2023; Hasan and Miah, 2014). Discharge of oil pollutants from the oil industries in the mangrove water could be responsible for the high DO level in the water. Biochemical oxygen demand (BOD) refers to the amount of oxygen required to decompose organic pollutants presence in water (Sri-Dattatreya *et al.,* 2018; Amadi *et al.,* 2010). It is affected by many factors including the temperature, extent of biochemical activities, and concentration of organic substances (Muduli and Panda, 2010). In the current study, the mangrove water exhibited a high level of BOD above the WHO recommended limit (6.0 mg/L) (WHO 2017a; 2017b). This finding is in agreement with the findings of Okabekwa *et al.* (2024), Azuamaha *et al.* (2023), and Edori and Nna (2018) who reported a high BOD values above the WHO guideline. Research showed that oil split into water increases the organic constituent resulting to increase in the BOD level (Azuamaha *et al.,* 2023). The higher level of BOD observed could be attributed to the large amount of organic pollutants in the water body due to the oil activities in nearby areas. Chemical oxygen demand (COD) refers to the measure of water pollutants by the chemical decomposition of organic and inorganic matters (Waziri and Ogugbuaja, 2010). In the current study, the level of COD observed in the water sample is above the recommended value ((< 10 mg/L) set by WHO for domestic use and protection of aquatic organisms (WHO, 2017a; 2017b). A relevant study by Amadi et al. (2017) showed that Otamiri and Oramiri-Ukwa water bodies demonstrated a COD value within the range 10.20 mg/L to 50.00 mg/L. High level of COD in water bodies are associated with the presence of organic contaminants and remains of dead and decay aquatic organisms (Jamalianzadeh *et al.*, 2022). The elevated level of COD recorded in the water sample could be attributed to the presence of oil pollutants in the mangrove water.Alkalinity can be defined as the measure of ability of water to neutralize acids and it was mainly occurs due to the presence of carbonates and bicarbonates in water bodies (Igwe *et al.*, 2021). In this study the water sample demonstrated a high level of total above the permissible limit (120 mg/L) set by the WHO (2020). High level of bicarbonate was found in the water sample in the current study. This finding is in line with that of Dirisu and Olomukoro, (2015) who reported high level of bicarbonate in Agbede wetland, southern Nigeria. High level of bicarbonate is an indicator of hardness of water which has hazardous effects on the ecosystems (Mohammad *et al.*, 2013). The high level of alkalinity bicarbonate in the water sample could be attributed to the oil industrial activities in the nearby areas. This finding showed that the water sample demonstrated low level of sulphate below the limit values 250 mg/L, and 500 mg/L set by WHO (2017) and NESREA (2009), respectively. Sulphate in water is an important parameter that contributes to water acidity. High level of sulphate in water increases the acidity of water (Edori and Edori, 2021). High concentration of sulphate causes many adverse health effects including include purgation, lack of fluids in the body and abdominal irascibility (Omaka *et al.*, 2014). It has been reported that mining activities, manufacturing processes, paper milling and tanneries are major cause of high level of sulphate in water bodies (Edori and Edori, 2021). According to the WHO (2017) the standard maximum level of phosphate in water is 1 mg/L. In this study, the concentration of phosphate in the water sample exceeded the standard maximum level recommended by the world health organization. Elevated phosphates level is associated with significant changes in dissolved oxygen levels in water (Edoreh *et al.*, 2021). High level (44.383.3 mg/L) of phosphate has been reported in water body in related study (Ekevwe *et al.*, 2019). Nitrate is one of the common pollutants in surface and groundwater (Adimalla and Qian, 2019; Chen *et al.*, 2017). The level of nitrate in the water sample observed in the current study was above the maximum limit (10 mg/L) recommended by WHO (2017). High concentration of nitrate in water bodies is associated with increase total suspended solids of water (Bijay-Singh and Craswell, 2021). In this study, a high level of chloride was observed in the water sample and was below the maximum accepted chloride level (250 mg/L) in water (WHO, 2017). This finding is in line with the findings of the relevant studies by Gupta et al. (2016) and Sunday (2018) who reported low concentration of chloride in water than the WHO recommended limit. Chlorides presence in water bodies affected the nature and properties of water causing it unsafe for domestic uses (Azuamaha *et al.*, 2023). High concentration of chloride in water increases electrical conductivity of water (Kpee *et al.*, 2009). High level of chloride in water is an indicator of water pollution (Adimalla and Qian, 2019) and cause significant health hazards (Ojekunle, *et al.*, 2016). Many epidemiological studies showed that consumption of water contaminated with chlorine increases risk of colorectal and bladder cancer (DPR, 2018). The high chloride level in the water sample could be attributed to the water pollution caused by crude oil components discharge in the water due to the oil activities in the nearby area. In the present study, the water sample demonstrated high level of l lead, nickel, chromiun, cobalt, arsenic and cadmium above limit values set by FEPA (2003), NSDWQ (2017), and WHO (2021). Elevated level of heavy metals in water bodies causes serious effects to people using the water for domestic activities and/or consuming the aquatic organisms from the water (Al-Haidarey *et al.*, 2010). Study showed that heavy metals bio-accumulate in fish tissues thereby causing different physiological and behavioural effects (Ibemenuga e t al., 2019). It has been reported that elevated level of heavy metals in water can lead to the loss of biodiversity and degradation of habitats (Uwah *et al.*, 2013). Heavy metals including lead, nickel, chromiun, cobalt, arsenic and cadmium have been reported and documented to produce toxic effect on various organs and tissues in the body (Abubakar *et al.*, 2022). In this study the water sample exhibited a high concentration of naphthalene, acenaphthene, fluorine, acenaphthylene, anthracene, phenanthrene, and pyrene above the WHO recommended value (5 mg/L) for drinking water (WHO, 2011). This finding is in agreement with the findings by Anyakora and Coker (2006) who observed a high concentration of PAHs in crude oil contaminated water from the Niger Delta region above the WHO recommended value. Polycyclic aromatic hydrocarbons (PAHs) demonstrated toxic, mutagenic, teratogenic and carcinogenic properties and classified as the primary environmental pollutants (USEPA, 1984).

5. Conclusions

The levels of the physico-chemical parameters, heavy metals, and PAHs analyzed in this study were above and/or below the standard limits recommended by the national and/or international standard organizations or bodies for survival of aquatic organisms and domestic uses. High level of these parameters causes health adverse effects on human, plants animals, and aquatic organisms. Hence, the mangrove water is not recommended for consumption and domestic uses. There is a need for controlling the discharge pollutants in the mangrove water for sustainable pollution control.

References

Abali, C.I., Kpee, F., Orie, K.J. (2023). Physicochemical characteristics of surface water from Idu Ogba River, Rivers State, Nigeria. *FNAS Journal of Scientific Innovations*, 5(2), 69-77.

Abubakar, I., Danyaya, J.A., Abdullahi, Z., Zubairu, A., Sahabi, A.U., Ahmad, F. (2022). Phytochemical Screening, Nutritional and Anti-nutritional Composition of Aqueous Rhizome Extract of *Curcuma longa*. *J Biotechn Biochem*., 8(2), 1–9. http://dx.doi.org/10.9790/264X-08020109

Adegbite, K.A., Adekiya, A.O., Adebiyi, O.T.V., Alori, E.T., Ejue, W.S., Olayanju, A., Aremu, C. (2020). Baseline Fertility Status of a Gravelly Alfisol in a derived Savannah

Agro-Ecological Zone of Nigeria. *Open Agricultural Journal*, 5, 573–581.

Adesakin, T.A., Abayomi, T.O., Umar, B., Abubakar, N.M., Iduwo, A.A., Precious, Z.A., Niima, D.A., Ibrahim, B.B. (2020). Assessment of bacteriological quality and physico-chemical parameters of domestic water sources in Samaru community, Zaria, Northwest Nigeria. *Heliyon*. e04773 https://doi.org/./j.heliyon.2020.e04773

G., Alonso-Campos, V.A., MuñizSalazar, R., Ruiz-Fernández, A.C., Pérez-Bernal, L.H., Sánchez-Cabeza, J.A. (2020). Reserva de Carbón en un Ecosistema de Manglar al Norte de México: Cambios Ambientales Durante 35 Años. *Rev. Mex. Biodiv*., 91, 912910.

Akhtar, N., Syakir, M.I.I., Bhawani, S.A., Umar, K. (2021). Various natural and anthropogenic factors responsible for water quality degradation: A review. *Water*, 13(19), 2660. https://doi.org/10.3390/w13192660

Al-Haidarey, M.J.S., Hassan, F.M., Alkubaisey, A.R.A., Douabul, A.A.Z. (2010). The geoaccumulation index of some heavy metals in Al-Hawizeh Marsh, Iraq. *E-Journal of Chemistry*, 7(S1), S157 – S162.

Amadi, A.N., Olasehinde, P.I., Obaje, N.O., Unuevho, C.I., Yunusa, M.B., Keke, U., Ameh, I.M. (2017). Investigating the Quality of Groundwater from Hand-dug Wells in Lapai, Niger State, North-central Nigeria using Physico-chemical and Bacteriological Parameters. *Minna Journal of Geoscience*. 1(1), 77-92.

Adimalla, N., Qian, H. (20190. Groundwater quality evaluation using water quality index (WQI) for drinking purposes and human health risk (HHR) assessment in an agricultural region of Nanganur, south India. *Ecotoxicol. Environ. Saf.*, 176, 153–161. https://doi.org/10.1016/J.ECOENV.2019.03.066.

Agraz-Hernández, C.M., Chan-Keb, C.A., Chávez-Barrera, J., Osti-Sáenz, J., Expósito-Díaz,

Amadi, A.N., Olasehinde, P.I., Okosun, E.A., Yisa, J. (20100. Assessment of the Water Quality Index of Otamiri and Oramiriukwa Rivers. *Phys. Int*. 1, 116-123. doi: 10.3844/pisp.2010.116.123

Anyakora, C., Coker, H. (2006). Determination of polynuclear aromatic hydrocarbons (PAHs) in selected water bodies in the Niger Delta. *African Journal of Biotechnology*, 5(21), 2024 – 2031.

AOAC. (1990). Official Methods. Minerals, Official Methods of analysis, Washington, DC, USA. AOAC; 1990.

AOAC. (2000). Association of Official Analytical Chemist Official Methods of Analysis, New York, pp 66-89.

AOAC. (2005). Official Methods. Official Methods of analysis, 18th Ed. Washington, DC, USA. AOAC; 2005

APEC. (2011). APEC Water Systems: Free Drinking Water. Learn about water quality. http://www.freedrinkingwater.com/water_quality/q uality1/1-how-dissolved-oxygen-affects-waterquality.htm

APHA (American Public Health Association), (2001). Standard Methods for Examination of 560 Water American Public Health Association (APHA), Standard Methods for Examination of Water, Washington, D.C (2001).

APHA (American Public Health Association). (2005). Standard Methods for examination of Water and Wastewater. 21st Edn., American Public Health Association, Washington, DC., ISBN: 0875530478, pp: 2-61.

Asante, K.A., Yawson, D.O., Afari-Asiedu, S., Kyei, K.A., Asante, H. (2020). Assessment of the physico-chemical and bacteriological qualities of sachet water sold in the Cape Coast Metropolis of Ghana. *Environmental Systems Research*, 9(1), 1-13.

ASTM (American Society for Testing and Materials). (2004). Standard methods for acidity or alkality of water. Publ.D1067-70 (reapproved 1977), American soc. Testing and materials Philadelphia.pa.

ASTM (American Society for Testing and Materials). (2011). Standard Test Method for substances in Crude Oil. ASTM International, West Conshohocken, PA, 2011, *Annual Book of Standards*, 2, 287, 97, 93, 445. doi:10.1520/C0033-03, www.astm.org.

Azuamaha, K.O., Appiah-Effaha, E., Akodwaa-Boadi, K. (2023). Water quality index, ecotoxicology and human health risk modelling of surface and groundwater along illegal crude oil refining sites in a developing economy. *Heliyon*. 9, 20631. https://doi.org/10.1016/j.heliyon.2023.e20631

Babalola, T., Oluwatuyi, M., Sam-Ijadele, K. (2024). Physico-Chemical and Bacteriological Quality of Household Drinking Water from Source to Point of Use in Akewu Community in Ibadan, Oyo State, Southwest, Nigeria. *International Journal of Research and Scientific Innovation*, 21(17), 106 – 122. doi: https://doi.org/10.51244/IJRSI.2024.1104008

Baird, R.B., Eaton, A.D., Rice, E.W. (2017). Standard Methods for the Examination of Water and Wastewater . 23rd Edition, American Public Health Association (APHA), American Water Works Association (AWWA), and Water Environment Federation (WEF), Washington, D.C., USA.

Barmon, P.C., Islam, M.S., Kabir, M.H. (2018). Physicochemical parameters and heavy metal concentration in water at the Mokeshbeel of Bangladesh. *Journal of Environmental Science and Natural Resources*, 11, 1 – 8.

Bijay-Singh, A., Craswell, E. (2021). Fertilizers and nitrate pollution of surface and ground water: an increasingly pervasive global problem. *SN Applied Sciences*, 3(4), 518. https:// doi.org/10.1007/s42452-021-04521-8

Boyle, T.P., Fraleigh, H.D. (2003). Natural and anthropogenic factors affecting the structure of the benthic macro invertebrate community in an effluent-dominated reach of the santa cruz river, AZ. *Ecological Indicators*, 3, 93 – 117.

Carr, G.M., Neary, J.P. (2006). Water quality for ecosystem and human health. United Nations Environment Program Global Environment Monitoring System/Water Program, Burlington, Ontario, Canada.

Chen, J., Wu, H., Qian, H., Gao, Y. (2017). Assessing nitrate and fluoride contaminants in drinking water and their health risk of Rural Residents living in a semiarid region of northwest China, *Expo Health*, 9 (3), 183–195. https://doi.org/10.1007/s12403-016-0231-9

Dirisu, A.R., Olomukoro, J.O. (2015). Investigation of Water Quality of two Rivers in Agbede – Wetlands in Southern Nigeria. Glob. *NEST J*, 17(3), 451-462.

Dorleku, M. (2013). Groundwater contamination with toxic metals through small scale mining within the Lower Pra Basin. Master's Thesis, University of Ghana, Legon, Ghana.

DPR (Department of Petroleum Resources). (2018). Environmental Guidelines and Standards for the Petroleum Industry in Nigeria (EGASPIN). 3rd Edition, Department of Petroleum Resources, Lagos.

Edoreh, J.A.I., Moobe, T.O.T., Ikpokpo, E., Ubrei-Joe, M.M., Ubrei-Joe, C.M. (2021). Zooplankton Diversity, Dynamics and Correlation with Physicochemical Parameters at Ugbevwe Pond in Delta State, Nigeria. *Journal of Applied Sciences and Environmental Management*. 25(6), 1047-1052.

Edori, O.S., Edori, E.S. (2021b). Evaluation of Physicochemical Characteristics of Surface Water from Orashi River, Rivers State, Southern Nigeria. *Athens Journal of Sciences*, 8(2), 105-122.

Edori, O.S., Iyama, W.A., Amadi, M.C. (2020). Variation of Some Physicochemical Parameters of Surface Water of Elelenwo River, Rivers State, Niger Delta, Nigeria. *International Journal of Research and Scientific Innovation*, 7(5), 230 – 235.

Edori, O.S., Nna, P.J. (2018). Determination of physicochemical parameters of effluents at discharge points into the new Calabar river along Rumuolumeni axis, Port Harcourt, Rivers State, Niger Delta, Nigeria. *J. Environ. Anal. Toxicol*, 8(585), 23 – 29.

Ekemube, A.R., Emeka, C., Nweke, B., Atta, T.A., Opurum, N.A. (2022). Evaluation of Simulated Petroleum Hydrocarbon on the Physicochemical Properties of Soil. *Research Journal of Ecology and Environmental Sciences*, 2(4), 195 – 210. doi:10.31586/rjees.2022.365

Ekevwe, A., Aloba, I., Mathew, O., Aroh, A.O. (2019). Comparative Physicochemical Pollution Index of Rivers along River Jakara and Its Tributaries. *East African Scholars Journal of Agriculture and Life Sciences*, 2(20), 88 – 91.

EPA. (1984). Method Study 20, Method 610 (PNA's) EPA 600/4-84-063 National Technical Information Service, PB-, Springfield, Virgina 22161.

Erefitei, A. (2016). Bayelsa State Forest Management http://www.bodmasnewsblog.com/2016/05/bayelsa-state-forest-management.html

Ezzat, S.M., Mahdy, H.M., Abo-State, M.A., Abd El-Shakour, E.H., ElBahnasawy, M.A. (2012). Water quality assessment of river Nile at rosetta branch: Impact of drains discharge. *Middle East Journal of Scientific Research*, 12, 413-423.

Federal Environmental Protection Agency. (2003). Guidelines and standards for environmental pollution control in Nigeria. Lagos: FEPA.

Firmin, S.L., Jacqueline, D., Frank, D., Philippe, D., Marc, O., Philippe, T. (2016). Biodegradation of Polycyclic Aromatic Hydrocarbons in Mangrove Sediments Under Different Strategies: Natural Attenuation, Biostimulation, and Bioaugmentation with Rhodococcus erythropolis T902. *Water Air Soil Pollut*., 227(297), 1 – 15. doi:10.1007/s11270-016-2999-4

Gad, M., Saleh, A.H., Hussein, H., Farouk, M., Elsayed, S. (2022). Appraisal of surface water quality of nile river using water quality indices, spectral signature and multivariate modeling, Water (Switzerland) 14(7), w14071131. https://doi.org/10.3390/w14071131

Gupta, A., Bhatnagar, P., Bakre, P.P. (2016). Physicochemical properties of water and heavy metals (lead and zinc) in water and sediment of a reservoir and drainage of Jaipur (Rajasthan) - a comparative study. *Int. J. Fish. Aqua*, 4(5), 407-412.

Gwary, K.M., Zaria, U.A., Galadima, M.S., Diya'Uddeen, B.H. (2019). Soil and water contamination due to illegal artisanal Refinery activities: a case study of okarki community, Niger Delta area, Nigeria. Transactions of the VˇSB – Technical University of Ostrava Safety Engineering Series, 14(2), 17 – 24. https://doi. org/10.35182/tses-2019-0008.

Hasan, K., Miah, M. (2014). Impacts of textile dyeing industries effluents on surface water quality: a study on araihazar thana in narayanganj district of Bangladesh. *Journal of Environment and Human*, 2014 (3), 8–22. https://doi.org/10.15764/eh.2014.03002

Hasan, M.K., Shahriar, A., Jim, K.U. (2019). Water pollution in Bangladesh and its impact on public health. *Heliyon*, 5(8), e02145. https://doi.org/10.1016/ j.heliyon.2019.e02145

Ibemenuga, K.N., Ezike, F., Nwosu, M.C., Anyaegbunam, L.C., Okoye, E.I., Eyo, J.E. (2019). Bioaccumulation of some heavy metals in some organs of three selected fish of commercial importance from Niger River, Onitsha shelf, Anambra State, Nigeria. Journal of FisheriesSciences.com, 13(3), 1 – 12.

Igwe, O., Ngwoke, M., Ukah, B.U., Ubido, O.E. (2021). Assessment of the Physicochemical Characteristics of Groundwater and Soils around Oil-Producing Communities in Afam Area of Port Harcourt, Niger Delta Nigeria. *Applied Water Science*, 11(74), 93 – 96. https://doi.org/10.1007/s13201-021-01393-6

Islam, M.M., Borgqvist, H., Kumar, L. (2019). Monitoring Mangrove forest landcover changes in the coastline of Bangladesh from

1976 to 2015. *Geocarto Int*., 34, 1458 – 1476. 10.1080/1010.6049.2018.1489423

Iyama, W.A., Edori, O.S. (2013). Water quality index estimate for Isiodu River water during dredging in Niger Delta, Nigeria. *Global Journal of Pure and Applied Sciences*, 19, 163 – 167.

Iyama, W.A., Edori, O.S. (2014). Seasonal variation in water quality during dredging of brackish water habitat in the Niger Delta, Nigeria. *Trends in Applied Sciences Research*, 9(3), 153 – 159.

Jamalianzadeh, S.F., Rabieifar, H., Afrous, A., Hosseini, A., Ebrahimi, H. (2022). Modeling DO and BOD5 Changes in the Dez River by Using QUAL2Kw. *Pollution*, 8(1), 15 – 35.

Kamboj, N., Kamboj, V. (2019). Water quality assessment using overall index of pollution in riverbed-mining area of Ganga-River Haridwar, India. *Water Science*, 33(1), 65 – 74.

Khayan, K., Husodo, A.H., Astuti, I., Sudarmadji, S., Dhojan, T.S. (2019). Rainwater as a source of drinking water: health impacts and rainwater treatment. https://doi.org/10.1155/2019/1760950.

Kpee, F., Ozioma, E., Ihunwo, L. (2009). Seasonal variation of Cd, Ni, Cu and Pb in catfish, sediment and water samples from Ipo stream in Ikwerre District of Rivers State, Nigeria. *Journal of Applied Sciences and Environmental Management*, 13(2), 63 – 67.

Mohammad, M.R., Rahman, M.T., Mohammad, S.R., Farzana, R., Jasim, U.A., Begum, S., Mohammad, A.H. (2013). Water Quality of the World's Largest Mangrove Forest. *Canadian Chemical Transactions*, 1(2), 141 – 156.

Mohammed, A.G., Udebuani, A.C., Okechi, R.N. (2024). Physico-Chemical Properties and Bacteriological Analysis of Mangrove Water from Mangrove Forest of Gbaramatu Kingdom Delta, Nigeria. *Journal of Bioresources and Environmental Sciences*.

Muduli, B.P., Panda, C.R. (2010). Physicochemical properties of water collected from Dhamra Estuary. International Journal of Environmental Sciences. 1(3), 123 – 134.

Murdoch, T., Cheo, M., O'Laughlin, K. (2001). The stream keeper's field guide: Watershed inventory and stream monitoring methods. Adopt-A-Stream Foundation, Washington, USA.

Nasrabadi, T., Ruegner, H., Sirdari, Z.Z., Schwientek, M., Grathwohl, P. (2016). Using total suspended solids (TSS) and turbidity as proxies for evaluation of metal transport in river water. *Applied Geochemistry*, 68, 19.

National Environmental Standards and Regulations Enforcement Agency (NESREA). (2007). National environment (wetlands, river banks and lake shores protection) regulation. Published by NESREA (Establishment) Act 2007; c2009. 58 – 96.

Nigerian Standard for Drinking Water Quality (NSDWQ). (2017). Nigerian Industrial Standard (N1554), Abuja: NSDWQ

Nsude, O.P., Orie, K.J. (2022). Phytochemical constituent and anti-corrosion properties of the root extract of Phyllanthus mellerianus

(Nvo-nkwu) plant on mild steel in 1.5 M HCl medium. *Chemical Science International Journal*, 31(2), 21 – 34.

Ojekunle, O.Z. et al. (20160. Evaluation of surface water quality indices and ecological risk assessment for heavy metals in scrap yard neighbourhood, *SpringerPlus*, 5(560), 2158–2169. https://doi.org/10.1186/s40064-016-2158-9.

Okabekwa, V.C., Arinze, R.U., Tabugbo, B.I., Okafor, V.N. (2024). Assessment of Physicochemical Properties of Water From Eleme River, South-South Nigeria. *J. Chem. Soc. Nigeria*, 49(1), 13–22.

Omaka, O.N., Nwabue, F.I., Itumoh, E.J., Oroke, E.C., Igwe, D.O. (2014). Physicochemical parameters and nutrients variations of streams and rivers in Abakaliki, Ebonyi State, Nigeria. *Global Nest Journal*, 16(1), 114 – 123.

Onojake, M.C., Abrakasa, S. (2012). Multivariate Statistical Analysis on Pollution Level of Woji Otamiri-oche River in Port Harcourt, Nigeria. International Journal of Environment and Bioenergy, 2(1), 43 – 52.

Onwuka, C., Eboatu, A.N., Ajiwe, V.I.E., Morah, E.J. (2021). Pollution Studies on Soils from Crude Oil Producing Areas of Rivers State, Niger Delta Region, Nigeria. *Open Access Library Journal*, 8(9), 1 – 17.

Onyegeme-Okerenta, B.M., Obia, C., Wegwu, M.O. (2016). Physicochemical properties of water quality of Imeh, Edegelem and Chokocho communities located along Otamiri-oche River in Etche Ethnic Nationality of Rivers State, Nigeria. *Journal of Applied Science and Environmental Management*, 20(1), 113–119.

Owhoeke, E., Ali, A., Nnaemeka, O.J., Orie, K.J., Ehiwario, J.N., Rashid, A. (2023). Index model equation analysis: A case study of the risk and source of inorganic contaminants in roadside uncontaminated soil of the Egi oil producing area, Niger Delta. *International Journal of Sediment Research*, 38(6), 891 – 900.

Owokotomo, A.I., Ajayi, O.O., Alabi, O.O., Chukwuka, A.V. (20200. Watershed land use, surface water vulnerability and public health risks of two urban rivers, Ado-Ekiti, South-West Nigeria. *SN Applied Sciences*, 2, 1-21.

Rahman, A.A., Abdullah, R., Wan-Mohtar, W.Y., Ismail, A.F., Jaafar, J., Ahmad, A.L. (2019). Factors affecting the quality of drinking water in Malaysia: A review. *Journal of Environmental Chemical Engineering*, 7(1), 102818

Rahmanian, N., Ali, S.H.B, Homayoonfard, M,, Ali, N.J., Rehan, M., Sadef, Y., Nizami, A.S. (2015). Analysis of Physiochemical Parameters to Evaluate the Drinking Water Quality in the State of Perak, Malaysia. *Journal of Chemistry*, 2(5) 11 – 15.

Ramkumar, T., Venkatramanan, S., Anithamary, I., Ibrahim, S.M.S. (2013). Evaluation of hydrogeochemical parameters and quality assessment of the groundwater in Kottur blocks, Tiruvarur district, Tamilnadu, India. *Arabian Journal of Geosciences*, 6, 101 – 108.

Rosli, N., Gandaseca, S., Ismail, J., Jailan, M.I. (20100. Comparative study of water quality at different peat swamp forest of Batang Igan Sibu Sarawak. *American Journal of Environmental Sciences*, 6, 416 – 421. doi:103844/ajessp.2010.416-421

Saoum, M.R., Sarkar, S.K. (2024). Monitoring mangrove forest change and its impacts on the environment. *Ecological Indicator*, 159, 111666. https://doi.org/10.1016./j.ecolind.2024.111666

Sekhar, P. (2020). Bacteriological characteristics of spring water in Ambo Town, West Shoa Zone, Oromia Region, Ethiopia. *Int J Environ Agric Res*, 6(11), 1–9.

Sharma, N., Walia, Y.K. (2017). Water quality investigation by physicochemical parameters of Satluj River (Himachal Pradesh, India). Current World Environment, 12, 174 – 180.

Shehu (2019). Water and sediment quality status of the Toplluha River in Kosovo. *J. of Ecol. Eng*. 20(11), 266 - 275.

Sohaib, M., Fahad, N.I., Al-Barakah, Hussein, M.M., Mazen, A., Ibrahim, A. (2023). Ecological assessment of physico-chemical properties in mangrove environments along the Arabian Gulf and the Red Sea coasts of Saudi Arabia. *Egyptian Journal of Aquatic Research*, 49, 9 – 16. https://doi.org/10.1016/j.ejar.2022.11.002

Sri-Dattatreya, P., Madhavil, K., Satyanarayana, B., Amin, A., Harini, C. (2018). Assessment of Physico-chemical Characteristics of Mangrove Region in the Krishnapatnam Coast, India. *International Journal of Current Microbiology and Applied Sciences*, 7(5), 2319 – 7706. https://doi.org/10.20546/ijcmas.2018.705.268

Standard Organization of Nigeria (SON). (2007). Standard Organization of Nigeria (SON). Nigerian Standard for Drinking Water Quality, SON, Abuja. Nigeria (2007).

Sunday, M. (2018). Determination of Physicochemical Properties and Heavy Metal Contents in Water, Sediment and Fish in Water and Food Crops in Zamfara State, Nigeria, Ph.D. Dissertation. Ahmadu Bello University: Zaria, Nigeria. 253p.

Syeed, M.M.M., Hossain, M.S., Karim, M.R., Uddin, M.F., Hasan, M., Khan, R.H. (2023). Surface water quality profiling using the water quality index, pollution index and statistical methods: A critical review. *Environmental and Sustainability Indicators*, 18, 100247. https://doi.org/10.1016/j.indic.2023.100247

Tawati, F., Risjani, Y., Djati, M.S., Yanuwiadi, B., Leksono, A.S. (2018). The analysis of the physical and chemical properties of the water quality in the rainy season in the sumber maron river- Kepanjen, Malang-Indonesia. Resources and Environment 8, 1 – 5.

Tesfaye, E., Berhe, A., Terle, D. (2018). Physicochemical analysis of Baro River Water and Other Potable Water of Gambella Town, Ethiopia. *Int. J. Adv. Res*, 6(12), 628–637. doi: 10.21474/IJAR01/8182.

Thirupathaiah, M., Samatha, C., Sammaiah, C. (2012). Analysis of water quality using physicochemical parameters in lower Manair reservoir of Karimnagar district, Andhra Pradesh. *International Journal of Environmental Sciences*, 3, 369-378.

Uddin, M.J., Jeong, Y.K. (2021). Urban river pollution in Bangladesh during last 40 years: Potential public health and ecological risk, present policy, and future prospects toward smart water management. *Heliyon*, 7(2), e06107. https://doi.org/10.1016/j.heliyon.2021.e06107

UNICEF/WHO (United Nations Children's Fund/World Health Organization). (2023). Progress on Household Drinking Water, Sanitation and Hygiene 2000–2022: Special Focus on Gender. New York, UNICEF/WHO. www.who.int/publications/m/item/progress-on-household-drinking-water-sanitation-and-hygiene-2000-2022---special-focus-on-gender.

US Environmental Protection Agency (USEPA). (1984). Health Effects Assessment for Polycyclic Aromatic Hydrocarbons (PAH). Environmental Criteria and Assessment Office. EPA 540/1-86-013, Washington DC

Uwah, I.E., Dan, S.F., Etiuma, R.A., Umoh, U.E. (2013). Evaluation of status of heavy metals pollution of sediments in Qua-Iboe River estuary and associated creeks, South-Eastern Nigeria. *Environment and Pollution*, 2(4), 110 – 122.

Waziri M, Ogugbuaja VO. 2010. Interrelationship between physicochemical water pollution indicators: A case study of River Yobe-Nigeria. American Journal of Science and Industrial Research. 1: 76-80.

World Health Organisation (WHO). (2017). Guidelines for Drinking Water Quality, 4th Edition. World Health Organisation: Geneva, Switzerland. 631p. https://iris.who.int/bitstream/handle/10665/254637/9789241549950-eng.pdf?sequence=1

World Health Organization (WHO). (2011). Guidelines for drinking-water quality (4th ed.). Geneva: World Health Organization.

World Health Organization (WHO). (2015). Water Sanitation and Health. http://www.who.int/water_sanitation_health/diseases

World Health Organization (WHO). (2017a). Guidelines for drinking-water quality: Fourth edition incorporating the first addendum. World Health Organization, Geneva. https://www.who.int/publications/i/item/9789241549950.

World Health Organization (WHO). (2017b). UN-water global analysis and assessment of sanitation and drinking water (GLAAS) 2017 report: Financing universal water, sanitation, and hygiene under the sustainable development goals. World Health Organization, Geneva.

World Health Organization (WHO). 2017c. Guidelines for Drinking-Water Quality: Fourth Edition Incorporating the First Addendum, https://www.who.int/publications/i/item/9789241549950.

World Health Organization (WHO). 2020. Guidelines for Drinking Water Quality. Geneva.

World Health Organization (WHO). 2021. A global overview of national regulations and standards for drinking-water quality (2nd ed.). Geneva: World Health Organization. ISBN 978-92-4-002364-2.

Zhang, B., Matchinski, E.J., Chen, B., Ye, X., Jing, L., Lee, K. (2019). Marine Oil Spills Oil Pollution, Sources and Effects. World Seas: An Environmental Evaluation. 391–406. doi:10.1016/b978-0-12-805052-1.00024.