Doi: 10.14710/jbes.2025.19942

Journal of Bioresources and Environmental Sciences, 2025, 4(1), 28-45

Research Article

Physico-Chemical Properties and Bacteriological Analysis of Mangrove Water from Mangrove Forest of Gbaramatu Kingdom Delta, Nigeria

Mohammed Abdulganiyu Galadima*, Udebuani Angela Chika[1], Okechi Reuben Nwoye

Department of Biotechnology, School of Biological Sciences, Federal University of Technology, Owerri, Imo, Nigeria

*Correspondence: amgaladima001@gmail.com

Received: 30th June 2024
Accepted: 31st October 2024
Published: 1st April 2025

Copyright: © 2025 by the authors. This work is under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Abstract. Mangrove water is a habitat for aquatic organisms and is important for water supply, transportation, agricultural and industrial activities. This study aims to evaluate the physico-chemical properties of mangrove water from the mangrove forest of Gbaramatu Kingdom Warri South West LGA, Delta State, Nigeria. The physical and chemical properties of the mangrove water sample were determined using standard AOAC, APHA, and ASTM methods. The enumeration of total heterotrophic bacteria in the mangrove water sample was evaluated using the colony-forming units (CFU) method. Bacterial isolates were identified and characterized by colony and morphology characteristics, microscopic examinations and biochemical tests. The mangrove water demonstrated 33 °C, 8.3, 35.63 NTU, 23915.53 µS/cm, 2213.13 mg/L, 10411.99 mg/L, 38.40 mg/L, 18545.11 mg/L, 5.40 mg/L, 18.51 mg/L, and 52.00 mg/L mean value of temperature, pH, turbidity, conductivity, salinity, TH, TSS, TDS, DO, BOD, and COD, respectively. The concentrations of total alkalinity, bicarbonate, chloride, sulphates, phosphate, and nitrate in the mangrove water were 142.15 mg/L, 110.05 mg/L, 349.97 mg/L, 278.05 mg/L, 1.50 mg/L, and 0.07 mg/L, respectively. The mangrove water sample contains a highly significant number of heterotrophic bacteria. The values of physical and chemical parameters in the mangrove water sample are above the recommended values by WHO for drinking and domestic uses.

Keywords: Bacteria, Gbaramatu, Mangrove forest, Niger Delta, Water

1. Introduction

Mangrove forests remain the most productive environments in the world. Mangroves are woody trees and shrubs that grow in specific intertidal environments and cover nearly 60–70 % of the Earth's tropical and subtropical coastal areas (Sohaib *et al.*, 2023). Mangroves occupy about 137,760km worldwide, comprising 57,859 km (42 %) in Asia, 27,552 km (20 %) in Africa, 20,664 km (15 %) in North and Central America, 16,531 km (12 %) in Oceania, and 15,153 km (11 %) in South America (Sohaib *et al.*, 2023; Hossain and Nuruddin, 2016). Mangrove forests are important portions of aquatic ecosystems that provide various ecological services for life well-being (James *et al.*, 2013). They are specific coastal environments that thrive in the warm, wet conditions of the tropics and subtropics (Saoum and Sarkar, 2024). Mangrove forests provide many benefits including nutrient cycling (Kim *et al.*, 2016), bioremediation as well as phytoremediation of heavy metal pollutants (Usman *et al.*, 2013), source of potential plant extracts (Sohaib *et al.*, 2022a), host for diversity of microorganisms (Sohaib *et al.*, 2022b), source of novel commercial products, aids host plant survival (Alarfaj *et al.*, 2015, Ameen *et al.*, 2016, Bibi *et al.*, 2017), and acts as carbon sink (Donato *et al.*, 2011). Mangrove forests are nursery grounds for commercially and recreationally valued species, landing points for migratory birds, filtration of sediment, nutrients and pollutants, enhancement of coastal fisheries, and protect coastlines against natural disasters such as floods, waves and extreme weather conditions (Islam *et al.*, 2019; Huxham *et al.*, 2015, Barbier, 2016). Other benefits of mangrove forests include erosion control and carbon sequestration (Saoum and Sarkar, 2024). Mangrove forests have the potential to sequester about 22.8 million metric tons of carbon each year (Sohaib *et al.*, 2023; Giri *et al.*, 2011). However, water's physical and chemical properties 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).

Water is the most abundant substance on the Earth and covers more than 70% of the Earth. Water constitutes about 2.8% freshwater (20% groundwater) and 97.2% saltwater (Gupta and Gupta, 2015). Water is important for human and animal survival, growth, and reproduction. Water is a habitat for aquatic organisms and an important body for transportation, agricultural, and industrial activities. Ground and surface water have been specifically used for domestic and/or industrial consumption. Surface water has been contaminated by crude oil activities, agricultural practices, urban solid waste disposal, and improper disposal of industrial effluent (Howladar *et al.*, 2021). The major causes of surface water pollution are crude oil spills, solid wastes, gaseous emissions, untreated industrial effluents, improper home waste disposal, and agricultural run-off (Uddin and Jeong, 2021; Akhtar *et al.*, 2021; Hasan *et al.*, 2019). Water quality has been adopted as a sustainable goal: "Ensure availability and sustainable management of water and sanitation for all" in the meeting of UN members (held in September 2015) for the 2030 Agenda (UNSD, 2015). Water quality depends on the composition of water and/or substances present in water and affects aquatic organisms's life, human life, animal health, and agricultural and industrial activities (Zabbey and Arimoro, 2017). United Nations General Assembly in July 2016 (UN, 2016) emphasized the consumption of clean and safe water and declared a human right to access quality water (UN, 2016).

Water pollution remains a global concern and a major public health problem in developing countries. Environmental pollution, including water pollution from petroleum hydrocarbons, has been causing environmental destruction, including mangrove forests, water, soil, air, and biota (Onwuka *et al.*, 2021; Adegbite *et al.*, 2020). Water pollution causes changes in the physical, chemical, and biological properties of water bodies to the extent that water is not potable for consumption and domestic uses. Reports showed that about 190 million diseases are associated with the consumption of contaminated water (Azuamaha *et al.*, 2023; Wang and Yang, 2016), and polluted water has caused about 2.2 million deaths, of which 1.4 million are children worldwide (WHO, 2015). In developing countries, including Nigeria, about 80% of diseases and more than 33% of deaths are associated with consumption of heavy metals contaminated water (Azuamaha *et al.*, 2023; Anake *et al.*, 2014). Surface water pollution has been one of the most serious environmental issues in the Niger Delta region (Amarachi *et al.*, 2023; Olalekan *et al.*, 2018).

Nigeria is one of the top oil-rich countries in the world and has beautiful landmarks such as mangrove forests. Niger Delta is the largest wetland in Africa and one of the largest wetlands in the world. The region has vegetation that covers a 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 took place in the Niger Delta region. Crude oil exploration and production activities have been causing water pollution by generating different pollutants, including hydrocarbon components, heavy metals, polycyclic aromatic hydrocarbons (PAHs), and many other toxic substances into different water bodies and groundwater sources (Azuamaha *et al.*, 2023; Gwary *et al.*, 2019). Persistent organic pollutants, including hydrocarbons (aliphatic and aromatic) and polycyclic aromatic hydrocarbons (PAHs), cause long-term ecological damage and health hazards for humans, animals, and aquatic organisms (Löffler *et al.*, 2023; Ankley *et al.*, 2020; Mojiri *et al.*, 2019). Niger Delta region is one of the fifth most severely petroleum-polluted environments in the world (Azuamaha *et al.*, 2023; Kadafa and Ayuba, 2012). It has been reported that about 0.7 – 1.7 million tons of crude oil spilled into water bodies, including mangrove water, oceans, rivers, and agricultural soils each year in the Niger Delta region (Ekemube *et al.*, 2022). The activities of crude oil production and refining in the Niger Delta have increased, causing more water pollution and serious health problems for humans, animals, and aquatic life. The oil activities in the region have significantly caused the destruction of mangrove forests, water bodies, and groundwater sources (Gwary *et al.*, 2019). The activities also affect the economic activities, including farming and fishing, leading to food shortages and unemployment in the region. This study aims to evaluate the physico-chemical properties and microbial load of the mangrove water from the mangrove forest of Gbaramatu Kingdom Warri South West Local Government Area, Delta State, Nigeria. This study helps to understand the trends, reduces the challenges associated with quality water, and ensures safe and healthy water resources.

2. Method

2.1. Study Area

This study was conducted in the Gbaramatu Kingdom. Gbaramatu Kingdom is a coastal community in Warri South West Local Government Area, Delta State, Nigeria. Gbaramatu Kingdom is one of the Ijaw kingdoms in Warri South-West Local Government Area of Delta State. The kingdom is along the Escravos River in Warri South-West LGA of Delta. The area is hailed by Tompoloand, located on Latitude 44°48'17"N and Longitude 6°04"E. Many of the communities in the area are often completely surrounded by water. The Ijaw kingdoms have been polluted by crude oil activities by the Nigerian National Petroleum Corporation (NNPC) Limited.

@The Author(s). 2025. Published by CBIORE

2.2. Collection of Mangrove Water Sample

The water sample was collected from the mangrove forest of Gbaramatu Kingdom, Wari South West LGA, Delta State, Nigeria. The sample was collected randomly with a mini-shipek grab sampler from the seawater into a sterile bottle. The sample was homogenized for a total distribution of contaminants and transported to the laboratory at 4 °C in an ice pack for analysis.

2.3. Determination of Physical Properties of the Mangrove Water

Determination of Colour and Odour

Preparation The color and odor of the mangrove water sample were evaluated by the physical observation and smelling organ, respectively.

Determination of pH

The pH value of the mangrove water was determined using a digital pH meter based on the reaction of hydrogen or hydroxide ion concentration with buffer solution to produce acidity or alkalinity (AOAC, 2000). The pH of the sample was measured in triplicate, and the mean pH value was obtained through statistical analysis.

Determination of Temperature

A standard digital centigrade mercury thermometer was used for the determination of the temperature of the mangrove water in degrees Celsius (^{0}C). The temperature was measured three times, and the average value was calculated.

Determination of the Salinity

The salinity of the mangrove water was determined by titration method using a combined ring silver coated electrode. One mile of the water sample was transferred into a 20 ml volumetric flask and made up to the mark with distilled water. The potassium dichromate indicator (1 ml) was added to the flask and shaken gently. The solution was titrated with silver nitrate until the color changed to red brick. The titration was carried out up to three times, and the salinity was calculated using Equation 1.

$$\text{Salinity (mg/L)} = \frac{\text{A X N 58.5 X 1000}}{\text{Volume of Sample (mL)}} \quad (1)$$

Where A is the volume of silver nitrate, and N is the molarity of silver nitrate

Determination of Electrical Conductivity

The electrical conductivity of the mangrove water was determined using a digital conductivity meter calibrated with the buffer solution. The conductivity of the water was measured by immersing the meter probe into the water sample in a beaker. The conductivity values were measured and recorded in triplicate, and the mean value was calculated using statistical software.

Determination of Turbidity

A standardized digital turbidity meter was used to measure the turbidity of mangrove water. The turbidity of the water sample was measured in the Nephelometric Turbidity Unit (NTU) up to three times, and the average value was obtained.

Determination of Total Hardness ($CaCO_3$)

The total hardness of the mangrove water was determined by titration method as described by Orewale *et al.* (2007) (Equation 2). The principle of the technique involves the reaction of calcium and magnesium with EDTA to form a chelate complex, which reacts with the Eriochromate Black T indicator to form a bluish-green (Orewale *et al.*, 2007). Twenty miles of the water sample was quantitatively transferred into a 250 ml conical flask. Five miles of buffer solution (0.01% w/v) and three drops of Eriochrome Black T indicator were added and thoroughly mixed. The solution was titrated with the 0.01% w/v mol EDTA solution to faint blue. The experiment was performed in triplicate, and the mean titre value was obtained and recorded.

@The Author(s). 2025. Published by CBIORE

$$\text{Total hardness (mg/L)} = \frac{\text{Molarity}}{\text{Volume of Sample (mL)}} \text{ X } 1000 \quad (2)$$

Determination of Total Suspended Solids (TSSs)

The total suspended solids of the mangrove water sample were determined by gravimetric technique as described by AOAC (2000). One hundred miles of the water sample was passed through the glass fiber filter apparatus. The residue obtained was dried overnight in an oven from 103^{0}C to 105^{0}C and weighed. The total suspended solids were obtained using Equation 3.

$$\text{Total suspended solids (mg/L)} = \frac{\text{Weight of dried residue (mg)}}{\text{Volume of sample filtered (mL)}} \text{X } 1000 \quad (3)$$

Determination of Total Dissolved Solids (TDSs)

The gravimetric method was used in the determination of the total dissolved solids of the mangrove water sample according to the method of AOAC (2000). The water sample (100 ml) was transferred into a pre-weighed evaporating dish and then dried in an oven at a temperature of 103 to 105°C for 24 hours. The dish was transferred into desiccators, allowed to cool at room temperature, and weighed. The total dissolved solids content was calculated using Equation 4.

$$\text{Total dissolved solids (mg/L)} = \frac{\text{W2}-\text{W1 (mg)}}{\text{Volume (mL)}} \text{ X } 1000 \quad (4)$$

W_1 is the weight of the empty dish, and W_2 is the weight of the empty dish + dry residue.

Determination of Dissolved Oxygen

The dissolved oxygen of the mangrove water was determined using the Schott Gerate Dissolved Oxygen meter. Two hundred miles of the water sample was filled by overflowing in an airtight bottle of the specified volume. The dissolved oxygen meter was calibrated, and the dissolved oxygen value was read in triplicate. The average dissolved oxygen value of the sample was obtained.

Determination of Biological Oxygen Demand

The biological oxygen demand of the mangrove water was determined by dilution technique using a standard method (5-Day BOD Test). The method is based on the amount of oxygen consumed during a fixed period of 5 days, which is related to the amount of organic matter in the original sample. The water sample (200 mL) was filled by over-flowing in an airtight bottle of the specified size. The dissolved oxygen of the water sample was first measured using the Schott Gerate Dissolved Oxygen meter. The water sample was then incubated at 20^{0}C for 5 days. The dissolved oxygen of the water sample was measured again after 5 days. The BDO was calculated using Equation 5.

$$\text{BOD}_5 \text{ (mg/L)} = [\text{DO}_1 - \text{DO}_0]/\text{ B} \quad (5)$$

DO_0 is the initial dissolved oxygen (immediately after preparation), DO_1 is the final dissolved oxygen (after 5 days of incubation), and B is the volume of sample used.

Determination of Chemical Oxygen Demand

The chemical oxygen demand of the mangrove water was determined by the Colorimetric method as described by ASTM (2011) and APHA (2005). The principle of the method involves the oxidation of organic and oxidizable inorganic substances present in water by a mixture of standard potassium dichromate acid solution (APHA, 2005). Dichromate is consumed in the oxidation of the organic matter, and the chemical oxygen demand is determined calorimetrically by measuring the increase in the green color of the reduced chromium (Cr^{3+}) or the decrease in the yellow color of the dichromate ($Cr_2O_7^{2-}$). The COD vial adapter was placed in the cell holder of the spectrophotometer. The spectrophotometer was blank to zero when the reagent blank was inserted. The vial containing the water sample was placed in the adapter. The COD value in mg/L was measured in triplicate, and the mean value was calculated.

2.4. Determination of Chemical Properties of Sediment and Water of Mangrove Forest

Determination of Total Alkalinity (CO_3 and HCO_3)

The total alkalinity of the mangrove water was determined by titration method as described by Hoko (2008). The method is based on the reaction of carbonates and sodium hydroxide to form bicarbonate, which reacts with phenolphthalein indicator to produce a pinkish colour. The water sample (50 ml) was transferred into a 250 ml conical flask.

@The Author(s). 2025. Published by CBIORE

Two drops of 0.5 % w/v phenolphthalein indicator were added and mixed thoroughly. The solution was titrated with 0.05 M H_2SO_4 to pinkish color as titer one (T_1). Two drops of 0.5%w/v methyl orange indicator were added to the pinkish solution and thoroughly mixed. The solution was titrated with 0.05M H_2SO_4 to pale red as titer two (T_2). The experiments were carried out in triplicate, and the titre mean values were recorded. The total alkalinity was calculated using Equation 6.

$$\text{Total alkalinity (mg/L)} = \frac{\text{Molarity (T1+T2)}}{\text{Volume of Sample(mL)}} \text{ X } 1000 \quad (6)$$

Determination of Bicarbonate

The American Public Health Association (APHA) (2005) titration method was used to determine the Bicarbonate level in the mangrove water. The water sample was titrated with standardized hydrochloric acid using methyl orange as an indicator, which turns yellow below pH 4.0. At this pH, the carbonic acid decomposes to give carbon dioxide and water. The titration was performed three times, and the average value was obtained.

Determination of Chloride

The concentration of chloride in the mangrove water was estimated using the titration method described by APHA (2005). The method is based on the formation of red-colored precipitate from the solution (APHA, 2005). The water sample (200mL) was titrated with a standardized silver nitrate solution using potassium chromate solution as an indicator. The titration was done in triplicate, and the average value was obtained.

Determination of Sulphate

The concentration of sulfate in the mangrove water sample was determined by the nephelometric technique. The method is based on the concentration of turbidity measured against the known concentration of prepared sulfate solution (APHA, 2005). Ten miles of the standard solution and distilled water were added to a 250ml flask containing 5.0ml of the conditioning reagent and stirred gently. The $BaCl_2$ (0.1-0.2g) was gently added into the flask. The Prepared solution was poured into the nephelometric cell and allowed to stand for five minutes. The Nephelometer was zeroed at 420nm with distilled water to obtain the absorbance of the standard. A similar experiment was carried out for the water sample. A standard curve was constructed, and the water sample's sulfate concentration was extrapolated. The experiments were conducted in triplicate, and the mean value was obtained.

Determination of Nitrate (NO_3^-)

The titration method described by Suthar *et al.*, 2009 was used for the determination of nitrate in the mangrove water sample. The method is based on the reaction of nitrate with brucine to produce a purple color (Suthar *et al.*, 2009). Ten miles of boric acid indicator was transferred into a 250 ml conical flask and connected to a Kjelder condenser, allowing steam to pass through. The water sample (50mL) was added to the macro kjelder flask. Then, MgO (0.2g) and Devada's alloy (0.4g) were added, thoroughly mixed, and connected to the Kjelder apparatus for 15 minutes. The solution was titrated with 0.01 M H_2SO_4 to a purple color. The experiment was conducted in triplicate, and the titre mean value was calculated and recorded. The amount of nitrate was calculated using Equation 7.

$$\text{Amount of nitrate (mg/L)} = \frac{\text{Molarity}}{\text{Volume of Sample (mL)}} \text{ X } 1000 \quad (7)$$

Determination of Phosphate

The phosphate level in the mangrove water sample was determined using the ASTM (2004) and APHA (1998). The method is based on the formation of yellow color by the action of phosphates on molybdate ions under strongly acidic conditions. The intensity of color is directly proportional to the concentration of phosphate in the sample (ASTM, 2004). The water sample (50 mL) was added to the flask containing 20 mL of the reagent solution (ascorbic acid). The standard solution was also added into another flask containing the reagent solution. The contents were incubated at 25°C for five minutes, and the absorbance was measured at a wavelength of 650 nm. The standard curve was constructed, and the concentration of phosphate was extrapolated.

2.5. Bacteriological Analysis

Isolation of Bacteria

@The Author(s). 2025. Published by CBIORE

The bacteria were isolated from the mangrove water sample using the method of Oparaocha *et al.* (2010) with some modifications. The water sample (10 ml) was transferred into a conical flask containing 90 ml of sterile peptone water. The contents were thoroughly mixed and diluted using the serial dilution technique. Each aliquot diluted sample (0.1 ml) was inoculated onto a pre-sterilized and solidified growth medium. The broth (100 μL) was spread on the surface of the solid agar media and then incubated at 30∘C for 10 days.

Identification and Characterization of Bacterial Isolates

The bacterial isolates were identified and characterized by colony and morphology characteristics, microscopic examinations, and biochemical tests. The color, shape, and motility of the bacterial isolates were physically observed using a magnification lens. The motility test and Gram staining were done according to the method by Oyeleke and Manga (2008). A smear of the pure isolates was prepared by placing a drop of normal saline on a clean slide. A sterile wire loop was used to pick a colony and emulsified on the slide. The smear was heated and fixed by passing the slide over a Bunsen flame. After fixation, the smear was covered with crystal violet for 30 seconds and then washed with sterile water. The iodine solution was applied for 60 seconds and washed with water. The smear was decolorized with ethanol, and it was added drop-wise on the slide until all free colour (blue) was removed and then rinsed with water. The slide was then flooded with Safranin (counter stain) for 30 seconds. The back of the slide was cleaned with cotton wool, allowed to air dry, and examined microscopically using oil immersion x100 objective. Different biochemical tests were done using standard methods, including catalase, citrate, indole, methyl red, Vorges-Proskauer, sugar fermentation, starch hydrolysis, and urea.

Enumeration of Bacterial Isolates

The enumeration of bacterial isolates in the mangrove water sample was evaluated using the colony-forming units (CFU) method as described by Cappello *et al.* (2012). The total quantity of bacterial isolates in the mangrove water sample was assessed by spreading aliquots of 100 µL of 10-fold diluent tubes on plates of nutrient agar medium. The plates were incubated at 30°C for 72 hours. The number of bacteria obtained was expressed as CFU/ ml (Cappello *et al.*, 2012).

3. Result and Discussion

3.1. Physical Properties of the Mangrove Water

The physical properties of the mangrove water sample are shown in Table 1. The physical appearance of the mangrove water is dark yellowish with characteristics of petroleum odor (i.e., repugnant, pleasant, and gasoline-like odor). The mangrove water exhibited 33 °C, 8.3, 35.63 NTU, 23915.53 µS/cm, 2213.13 mg/L, 10411.99 mg/L, 38.40 mg/L, 18545.11 mg/L, 5.40 mg/L, 18.51 mg/L, and 52.00 mg/L mean value of 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), respectively (Table 1).

The pH of water measures its acidity or alkalinity and determines the survival of aquatic life and biological activity (Azuamaha *et al.*, 2023). Water pH is regulated by the balance between carbon dioxide, carbonate, and bicarbonate ions, as well as other natural compounds such as humic and fulvic acids (Srilatha *et al.*, 2012). The value of pH in water is important to the health status of any aquatic system (Wang *et al.*, 2007). In this study, a high pH value (8.3) was observed in the mangrove water. The pH value obtained is within the limit range (6.5 – 8.5) set by WHO (2017a; 2017b) and USEPA (2012). Activities of oil industrial effluents and atmospheric deposition of acid-forming substances influence the pH value of water (Srilatha *et al.*, 2012). Similar studies by Kingsley *et al.* (2023) and Gijo *et al.* (2016) reported pH values ranging from 5.27 to 6.56, indicating an acidity of water. Consumption of acidic water may cause acidosis, leading to hyperventilation, impaired heart function, and low blood pressure (Wright, 2015). Acidic waters may cause dental erosion and teeth demineralization (Wright, 2015). The high pH value observed in this study could be attributed to the presence of petroleum components in the mangrove water due to the activities of crude production and refining in the area.

The temperature of water regulates the biological activities and governs the solubility of gases in water. Results of the present study showed that the mangrove water demonstrated a high-temperature value (33 °C). Similar studies showed that mangrove water temperature ranged from 26-29 °C during the northeast monsoon, 28 – 30 °C during the monsoon period, and 29 – 32 °C during the south-west monsoon (Kathiresan, 2001; Petronella *et al.*, 2009). Behera *et al.* (2008) noticed water temperatures ranging between 24.2 ∘C and 30.9 ∘C along the mangrove ecosystem of the Mahanadiriver delta. The temperature value obtained in this study is above the WHO (2017a; 2017b) recommended values (28 – 30 ∘C) for drinking water. This may be due to the effect of oil particles in the water.

@The Author(s). 2025. Published by CBIORE

Turbidity is a measure of water cloudiness due to suspended particles and precipitates of metals and/or organic substances (WHO, 2017c). Turbidity is an indicator of water quality and waste discharge with respect to colloidal matter. High turbidity of water indicates possible contamination, pollution, and water safety (Azuamaha *et al.,* 2023). High water turbidity can cause many environmental and health effects on biological systems. Turbidity is affected by the presence of suspended particles such as clay, silt, organic matter, plankton, and other microscopic or decomposer organisms in water (APHA, 2005; Yisa and Jimoh, 2010). The clarity of water decreased due to the presence of these suspended particles deposited in the water, resulting in high turbidity (Yisa and Jimoh, 2010). The turbidity level (35.63 NTU) obtained in this study was higher than the acceptable values (below 25 NTU) (Rosli *et al.,* 2010) for domestic use. Studies reported turbidity values ranging from 1.0 to 19.0 NTU in freshwater (Aigberua *et al.,* 2017; Moslen and Daka, 2016). Activities of oil exploration and refining, carbon depositions, organic compounds, and suspended particles have been causing high turbidity of water (Gad *et al.,* 2022). The high turbidity of the mangrove water recorded in this study could be due to suspended particles, particularly petroleum components in the mangrove water.

Electrical conductivity (EC) is the number of ions (positive and negative) in water and the water's ability to pass an electrical current (Sri-Dattatreya *et al.,* 2018). Electric conductivity measures the ionic concentrations of water induced by dissolved minerals (Azuamaha *et al.,* 2023). It is an indication of salinity as well as the total salt content of water (Sri-Dattatreya *et al.,* 2018). In the present study, high electrical conductivity (23915.53 μS/cm) was obtained in the mangrove water above the recommended values (1000 μS/cm) by the WHO (2017a); (2017b). Nature and acidic contents of pollutants, including petroleum components, cause higher conductivity of water (Saalidong *et al.,* 2022). The high electrical conductivity value could be attributed to the crude oil pollutants and minerals present in the mangrove water.

The hardness of water is caused by the presence of divalent cations, especially the calcium (Ca) and magnesium (Mg) ions. The result of the presence study indicated a 10411.99 mg/L total hardness of the mangrove water above the maximum limit of 300 mg/L recommended by WHO for drinking water (WHO, 2020). The result of this study is in line with the study by Vilas and Ashwinova (2015), who reported a total hardness of 1800 to 9200 mg/L in the Sunderban Mangrove ecosystem. However, Mariappan *et al.* (2016) reported a total hardness ranging from 680 to 6800 mg/L along the Pichavaram mangrove forest. High total hardness concentration is an indication of high amounts of calcium and magnesium ions, which can provide a significant supplementary contribution to total calcium and magnesium intake for aquatic life (Iorwua *et al.,* 2018; Sengupta, 2013). A report by the Agency for Toxic Substance and Disease Registry (ATSDR) (2012) showed that cardiovascular illnesses are associated with high hardness concentration. High hardness levels influence the system distribution issues and the effectiveness of soaps and detergents (Shigut, 2017). The high total hardness concentration of the mangrove water observed in this study could be due to the presence of petroleum hydrocarbons as well as the calcium and magnesium ions constituents.

Suspended solids are one of the natural pollutants in water bodies that cause turbidity in water bodies (Mahvi and Razazi, 2005). Total suspended solids include organic particles and minerals that are transported in the water. It has been reported that the TSS of normal water can range from less than 5 to 30,000 mg/L and vary between water bodies (UN GEMS/Water, 2005; Amadi *et al.,* 2010). However, WHO (2017a; 2017b) set 10 mg/L of TSS as the maximum recommended value for drinking water. In this study, the mangrove water exhibited a high level of TSS (38.40 mg/L) above the WHO recommended value (10 mg/L) (WHO, 2017a; 2017b). This study agrees with Okabekwa *et al.* (2024), who reported high TSS values (312.78 and 372.01 mg/L) in water stations. A high total suspended solids concentration causes high turbidity, restricting light penetration and hindering photosynthetic activity (Sri-Dattatreya *et al.,* 2018). The high TSS value recorded in the current study could be due to the high content of petroleum hydrocarbons in the water.

Total dissolved solids (TDS) are substances comprising inorganic particles and a small proportion of organic particles in water. Total Dissolved Solids (TDS) determine the palatability of water due to inorganic salts and minerals (Adimalla and Venkatayogi, 2018; Subba Rao *et al.,* 2017). The total dissolved solids (TDS) value (18545.11mg/L) obtained in this study is higher than the limit values of 600 and 500 mg/L recommended by WHO (2017a; 2017b) and USEPA (2012) for drinking water, respectively. The concentration of total dissolved solids in water is associated with water conductivity. Water's high conductivity indicates a high total dissolved solids level (Chauhan and Ramanathan, 2008). Contaminants from oil activities, wastewater, municipal and agricultural run-off, and industrial effluents are responsible for TDS in water bodies (Okabekwa *et al.,* 2024). The high TDS concentration recorded in the mangrove water could be attributed to its high conductivity as well as the petroleum components present in the water.

Dissolved oxygen (DO) is a volume of oxygen contained in the water (APEC, 2011). Dissolved oxygen is an important characteristic of water, and its concentration in water is an indicator of prevailing water quality, trophic status, and the ability of water to support a well-balanced aquatic life (Sri-Dattatreya *et al.,* 2018). Dissolved oxygen is essential for the respiratory metabolism of the entire aerobic aquatic life in the mangrove ecosystem (Sri-Dattatreya *et al.,* 2018). The amount of oxygen that water can hold depends on the water temperature, salinity, and pressure (APEC, 2011). The DO value (5.4 mg/L) obtained in this study is below the accepted value of 6 mg/L (WHO 2017a; 2017b). The present study's result aligns with the values reported in the relevant studies. Prabu *et al.* (2008) observed DO ranging from 2.4

@The Author(s). 2025. Published by CBIORE

to 5.0 mg/L in Pichavaram mangroves. Srilatha *et al.* (2013) reported DO from 3.92 to 5.22 mg/L and 3.97 to 5.33 mg/L in Point Calimere and Muthupettai mangroves, respectively. However, Srinivasan *et al.* (2013) reported DO values ranging from 5.5 to 6.4 mg/L in Vedaranyam mangroves. Low dissolved oxygen in water can stimulate anaerobic denitrification of nitrate to nitrite (Azuamaha *et al.*, 2023). Crude oil components inhibit the dissolution of atmospheric oxygen into water, reducing its freshness and quality (Azuamaha *et al.*, 2023; Hasan and Miah, 2014). The DO obtained in this study could be due to the discharge of crude oil components in the mangrove water.

Biochemical oxygen demand (BOD) refers to measuring the extent of organic pollution in water bodies (Sri-Dattatreya *et al.*, 2018). Biochemical oxygen demand determines aerobic microorganisms capable of degrading organic matter (Azuamaha *et al.*, 2023). The level of BOD provides information regarding the quality of water and helps in deciding the suitability of water for different uses (Sri-Dattatreya *et al.*, 2018). BOD is an indicator of the amount of oxygen required to decompose organic matter and the amount of biodegradable organic substances (Amadi *et al.*, 2010). BOD depends on temperature, the extent of biochemical activities, the concentration of organic matter, and other related factors (Muduli Bipra Prasanna *et al.*, 2010). BOD is also affected by many organic matters such as leaves, wood, wastewater, or urban stormwater run-off (Seca Gandaseca *et al.*, 2011). In the current study, the mangrove water demonstrated a high concentration of BOD (18.51 mg/L) above the WHO recommended limit (6.0 mg/L) (WHO 2017a; 2017b). The result of the present study is consistent with the findings of Okabekwa *et al.* (2024), Azuamaha *et al.* (2023), and Edori and Nna (2018), who reported high BOD values above the WHO guideline. Crude oil is rich in hydrocarbons, and when split into water, it increases the organic constituent, implicitly increasing the BOD (Azuamaha *et al.*, 2023). The high level of BOD in the mangrove water recorded in this study could be attributed to the petroleum hydrocarbon pollutants present in the water.

Chemical oxygen demand (COD) is the measure of water pollutants by referring to the chemical decomposition of organic and inorganic contamination (Waziri and Ogugbuaja, 2010). Chemical oxygen demand determines the total oxygen required for the chemical oxidation of biodegradable and non-biodegradable organic matter (USEPA, 2004). In this study, the average value of chemical oxygen demand (52.00 mg/L) in the petroleum-contaminated mangrove water is relatively high and above the WHO (2017a; 2017b) recommended value (< 10 mg/L) for drinking water. The result of this study is in agreement with the result recorded by Brima (2017). A high level of COD is an indicator of the presence of degradable and non-degradable organic matter and is associated with a decreased level of DO due to increased oxygen demand by bacteria consuming the organic matter. The high concentration of COD found in the presence study could be attributed to the presence of oil pollutants in the mangrove water.

Table 1, Physical Properties of the Mangrove Water

Parameter	Values
Color/Appearance	Dark yellowish
pH	8.30 ± 0.09
Temperature (°C)	33.00 ± 0.08
Turbidity (NTU)	35.63 ± 0.14
Conductivity (μS/cm)	23915.53 ± 0.29
Salinity (mg/L)	2213.13 ± 0.09
Total Hardness (mg/L)	10411.99 ± 0.04
Total Suspended Solids (mg/L)	38.40 ± 0.06
Total Dissolved Solids (mg/L)	18545.11 ± 0.09
Dissolved oxygen (mg/L)	5.40 ± 0.02
Biological Oxygen Demand (mg/L)	18.51 ± 0.01
Chemical Oxygen Demand (mg/L)	52.00 ± 0.57

Values are mean ± SEM (n = 3)

3.2. Chemical Properties of the Mangrove Water

Table 2 shows the chemical properties of the mangrove water sample. The average concentrations of total alkalinity, bicarbonate, chloride, sulfates, phosphate, and nitrate in the mangrove water were 142.15 mg/L, 110.05 mg/L, 349.97 mg/L, 78.05 mg/L, 1.50 mg/L, and 0.07 mg/L, respectively (Table 2).

@The Author(s). 2025. Published by CBIORE

Alkalinity is composed of primarily carbonate (CO_3^{2-}) and bicarbonate (HCO^{3-}). Alkalinity acts as a stabilizer for pH (Igwe *et al.,* 2021). Alkalinity is a measure of the capability of water to neutralize acids, and it largely occurs owing to the presence of carbonates and bicarbonates in the water (Igwe *et al.,* 2021). Alkalinity in groundwater has been found to range from 9.3 % - 18.6 % in Afam Rivers State (Igwe *et al.,* 2021). This study indicated a total alkalinity level of 142.15 mg/L in the mangrove water sample. This value is above the permissible limit of 120 mg/L set by the WHO (2020). The high level of total alkalinity in the mangrove water could be attributed to the crude oil and its components present in the water.

The presence of a high amount of bicarbonate indicates the hardness of water, which has hazardous effects on the ecosystems (Mohammad *et al.,* 2013). In this study, a high level (110.05 mg/L) of bicarbonate was observed in the water sample. This study is in agreement with that of Dirisu and Olomukoro (2015), who reported a relatively high level of bicarbonate in the Agbede wetland in southern Nigeria. The high concentration of bicarbonate in the water sample could be attributed to the oil industrial activities at the study site.

The salty taste of water is caused by the chloride content of water, especially when sodium is the predominant cation (Azuamaha *et al.,* 2023). In the present study, a high concentration (349.97 mg/L) of chloride was recorded in the mangrove water above the recommended value of 250 mg/L (WHO, 2017a; 2017b; USEPA, 2012). The result is in agreement with the study by Okabekwa *et al.* (2024) and Azuamaha *et al.* (2023), who observed that chloride values exceeded the WHO-recommended guideline values of 250 mg/L. A high level of chloride in water is an indicator of water pollution (Adimalla and Qian, 2019) and causes significant health hazards (Ojekunle *et al.,* 2016). Consumption of chlorinated water has been associated with an increased risk of colorectal and bladder cancer in numerous epidemiological studies (DPR, 2018). In the present study, the high concentration of chloride in the mangrove water could be due to the petroleum components present in the mangrove water.

Sulfate ions are naturally present in surface water bodies, especially crude oil-polluted water. The level (278.05 mg/L) of sulfate in the mangrove water is higher than the specified value of 200 mg/L by WHO (2017a) (2017b). This is in line with the studies by Azuamaha *et al.* (2023) and Ogamba *et al.* (2004), who reported high sulfate concentrations in surface water above the WHO (2017a; 2017b) recommended values of 200 mg/L. It has been reported that the consumption of water with high sulfate concentrations increases the risk of gastrointestinal diseases (Karavoltsos *et al.,* 2008). Studies showed that higher concentrations of sulfate in the oil spill-affected samples are likely to be due to oil pollution (Edema, 2012; Punmia *et al.,* 2007). The high concentration of sulfate in the mangrove water could be due to the crude oil and its components present in the water.

Results of the present study indicated that the mangrove water exhibited a high level (1.50 mg/L) of phosphate above the recommended limit range (0.01 – 0.02 mg/L) (APHA, 1998). The result of this study is in agreement with the study by Srilatha *et al.* (2013), who reported a high concentration of phosphate (0.470 to 2.620 µmol/L) in Calimere and Muthupettai mangroves above the guideline values. The high concentration of phosphate observed in this study could be attributed to the presence of crude oil components in the mangrove water.

Nitrate naturally occurs and remains one of the widespread sources of contamination of surface and groundwater (Adimalla and Qian, 2019; Chen *et al.,* 2017). In the present study, the level (0.07 mg/L) of nitrate observed in the mangrove water is below the WHO (2017a; 2017b) guideline values of 50 mg/L. The result of the present study is in agreement with similar studies by Gijo and Hart (2016), Srinivasan *et al.* (2013), Puyate and Rim-Rukeh (2010), and Ogamba *et al.* (2004), who observed nitrate levels in surface water below the WHO recommended value. High concentrations of nitrate in water have been associated with blue-baby syndrome in children (Azuamaha *et al.,* 2023). The low level of nitrate in the mangrove water could be due to the utilization of nitrate by crude oil-degrading bacteria in the mangrove water.

Table 2. Chemical Properties of the Mangrove Water

Parameter	Concentration (mg/L)
Total alkalinity	142.15 ± 0.061
Bicarbonate	110.05 ± 0.153
Chloride	349.97 ± 0.051
Sulphate	278.05 ± 0.056
Phosphate	1.50 ± 0.001
Nitrate	60.07 ± 0.003

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

@The Author(s). 2025. Published by CBIORE

3.3. Bacteriological Analysis

Enumeration of Heterotrophic Bacteria

In this study, the total bacteria counts in the mangrove water sample ranged from 2.35×10^2 cfu/ml. Seven different bacteria were isolated and identified, which are *Pseudomonas sp., Bacillus sp., Vibrio sp., Micrococcus sp., Citrobacter sp., Enterobacter sp., and Flavobacterium sp*.

Colony and Morphology Characteristics of the Bacterial Isolates

Table 3 shows the morphological characteristics of the bacterial isolates. The result showed that most of the isolates were Gram-negative, with only two isolates found to be Gram-positive. From the result, it was observed that the isolates were of different shapes and forms. Many of the isolates exhibited rod-shaped and motile characteristics (Table 3).

Table 3. Colony and Morphology Characteristics of the Bacterial Isolates

Isolate No	Identity of isolate	Colour of colony	Shape	Motility	Gram-staining
1	Pseudomonas sp.	Yellow-green	Rod	+	-
2	Bacillus sp.	Whitish	Rod	+	+
3	Vibrio sp.	White-yellowish	Rod	+	-
4	Micrococcus sp.	Yellow	Cocci	+	+
5	Citrobacter sp.	Yellow	Rod	+	-
6	Enterobacter sp.	Gray-yellowish	Rod	+	-
7	Flavobacterium sp.	Yellow-brown	Rod	+	-

Biochemical Characteristics of the Bacterial Isolates

The biochemical characteristics of the bacterial isolates are shown in Table 4. The bacterial isolates observed are *Pseudomonas sp., Bacillus sp., Vibrio sp., Micrococcus sp., Citrobacter sp., Enterobacter sp., and Flavobacterium sp*. (Table 4). The biochemical reactions showed that all the isolates are positive for catalase, starch hydrolysis, glucose, lactose, mannose, and sucrose. Also, all the isolates exhibited indole negative reactions. All the isolates except isolate 4 (*Micrococcus* species) are citrate-positive. With the exception of isolate 1 (*Pseudomonas sp*.) and 7 (*Flavobacterium sp*.), the whole isolates demonstrated methyl red negative reaction. The isolate 3 (*Vibrio sp*.), 5 (*Citrobacter sp*.), and 6 (*Enterobacter sp*.) are characterized by the H_2S production. The results also indicated that isolates 1 (*Pseudomonas sp*.), 3 (*Vibrio sp*.), 4 (*Micrococcus* species), and 7 (*Flavobacterium sp*.) are oxidase-positive. However, isolates 3 (Vibrio sp.) and 6 (Enterobacter sp.) exhibited positive Vogus Proskauer reactions (Table 4).

In this study, the high total quantity of heterotrophic bacteria *Pseudomonas sp., Bacillus sp., Vibrio sp., Micrococcus sp., Citrobacter sp., Enterobacter sp., and Flavobacterium sp*. was recorded in the mangrove water sample. *Pseudomonas* species are gram-negative bacteria commonly found in surface water bodies, including mangrove water. *Pseudomonas* species cause a variety of infections in both immunocompetent and immunocompromised hosts (Kerr and Snelling, 2009). Infections caused by Pseudomonads include folliculitis, puncture wounds leading to osteomyelitis, pneumonia, and otitis externa (Mulcahy *et al.,* 2014). *Pseudomonas* species commonly cause nosocomial infections like ventilator-associated pneumonia and catheter-associated urinary tract infections (Mulcahy *et al.,* 2014; Kerr and Snelling, 2009). *Pseudomonas* aeruginosa causes major health problems, including significant biotechnological and clinical burdens (Qin *et al.,* 2022). *Pseudomonas* fluorescens readily proliferates in aquatic environments and causes severe infections when consumed in water (Gołaś *et al.* 2019). *Vibrio* species are mainly found in surface waters, including salt water and brackish water. *Vibrio* infections are classified into cholera infections and noncholera infections. Generally, *Vibrio* infections are characterized by diarrhea, stomach cramps, nausea and vomiting, fever, chills, low blood pressure, and pain (NCEZID, 2024).

Bacillus species mainly cause anthrax disease. *Bacillus* species have been causing a variety of infections, which include abscesses, bacteremia/septicemia, wound and burn infections, ear infections, endocarditis, meningitis, ophthalmitis, osteomyelitis, peritonitis, and respiratory and urinary tract infections (Rachel *et al.,* 2023; Nguyen and Tallent, 2019; Hölzel *et al.,* 2018). The most frequently implicated infectious *Bacillus* species are *B. cereus, B. licheniformis,* and *B. subtilis*. Others *B. alvei, B. brevis, B. circulans, B. coagulans, B. macerans, B. pumilus, B. sphaericus,* and *B. thuringiensis* cause occasional infections (Rachel *et al*., 2023). *Bacillus* cereus can cause gastrointestinal syndromes characterized by diarrhea,

abdominal pain, nausea, and vomiting. *B. cereus* has also been implicated in infections of the eye, respiratory tract, and wounds (Nguyen and Tallent, 2019; Hölzel *et al.*, 2018). *Micrococcus* species are naturally found in environments including water resources and soil and comprise many members, including *Micrococcus* luteus. *Micrococcus* luteus is commonly found in human skin and oropharynx mucosa (Erbasan 2018). *Micrococcus* luteus causes infections such as hepatic and brain abscesses, native valve endocarditis, bacteremia, and septic arthritis (Erbasan, 2018; Ianniello *et al.*, 2019).

Citrobacter species are abundant in groundwater bodies, soil, foods, and the intestinal tracts of animals and humans (Cong'En *et al.*, 2014). *Citrobacter* species are opportunistic pathogens causing a variety of infections, including nosocomial infections (Dziri *et al.*, 2022; Rostamzad *et al.*, 2019; Nair *et al.*, 2020; Aguirre-Sánchez *et al.*, 2023; Heljanko *et al.*, 2023), sepsis, respiratory infections, UTIs, keratitis, and meningitis, especially in infants and immunocompromised adults (Jiménez *et al.*, 2017; Emery *et al.*, 2020; Urbinati *et al.*, 2023). However, diseases such as folliculitis, cellulitis, hives, ulcers, necrotizing fasciitis (Licata *et al.*, 2021; Moussa *et al.*, 2023), jaundice, ileus, abdominal pain, and/or gastrointestinal bleeding (Hewitt *et al.*, 2021), diabetes, hypertension, cancer, and liver cirrhosis have been associated with *Citrobacter* species. (Hashimoto *et al.*, 2021; Casas-Martínez *et al.*, 2023). *Enterobacter* consist about 22 species *E. cloacae, E. aerogenes, E. gergoviae,* and *E. agglomerans* (Rogers, 2024). Pathogenic *Enterobacter* causes a variety of infections, which include eye and skin infections, meningitis, bacteremia (bacterial blood infection), pneumonia, urinary tract infections, respiratory infections, soft tissue infections, osteomyelitis, and endocarditis (Rogers, 2024; Ramirez and Giron, 2023). The high population of heterotrophic bacteria in the mangrove water sample indicates the presence of high bacteria contamination and health risks for human consumption. The result of this study is in agreement with the report of Doughari *et al.* (2007), who found high total heterotrophic bacterial load in water and suggested that the water is unfit for human consumption.

Table 4. Biochemical characteristics of the bacterial isolates

Isolate No	Identity of Isolate	Cit	Cat	Ind	Met	H_2S	Oxd	Sta	Glu	Lac	Man	Suc	Ure	Vog
1	Pseudomonas sp.	+	+	-	-	-	+	+	+	+	+	+	+	-
2	Bacillus sp.	+	+	-	+	-	-	+	+	+	+	+	-	-
3	Vibrio sp.	+	+	-	+	+	+	+	+	+	+	+	+	+
4	Micrococcus sp.	-	+	-	+	-	+	+	+	+	+	+	+	-
5	Citrobacter sp.	+	+	-	+	+	-	+	+G	+	+	+	+	-
6	Enterobacter sp.	+	+	-	+	+	-	+	+G	+	+	+	+	+
7	Flavobacterium sp.	+	+	-	-	-	+	+	+	+	+	+	+	-

G (Positive with gas)

4. Conclusion

With the exception of the pH value, the level of all the physicochemical parameters analyzed in the mangrove water sample was above and/or below the standard limits recommended by the World Health Organization (WHO) for drinking water and domestic uses. Mangrove water contains a significant number of heterotrophic bacteria. The heterotrophic bacteria identified in the mangrove water were *Pseudomonas sp., Bacillus sp., Vibrio sp., Micrococcus sp., Citrobacter sp., Enterobacter sp., and Flavobacterium sp*. High levels of these parameters cause adverse health effects on humans, animals, and aquatic organisms. The contamination of the mangrove water causes serious impacts on the environment and the economic activities in the area. Thus, mangrove water is not recommended for drinking and domestic use. Therefore, there is a need for proper monitoring of the pollutant's discharge and sustainable remediation strategies.

Acknowledgment

Special thanks to the staff of the Microbiology and Chemistry Laboratory, Federal University of Technology, Owerri, Imo, Nigeria, for the experimental assistance.

@The Author(s). 2025. Published by CBIORE

References

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. https://doi.org/10.1515/opag-2020-0059

Adimalla, N., & Qian, H. (2019). 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.

Adimalla, N., Li, P., & Qian, H. (2019). Evaluation of groundwater contamination for fluoride and nitrate in semi-arid region of Nirmal Province, South India: a special emphasis on human health risk assessment (HHRA), *Human and Ecological Risk Assessment* 25 (5), 1107–1124. https://doi.org/10.1080/ 10807039.2018.1460579.

Adimalla, N., Li, P., & Venkatayogi, S. (2018). Hydrogeochemical evaluation of groundwater quality for drinking and irrigation purposes and integrated interpretation with water quality index studies, Environmental Processes 5 (2), 363–383, https://doi.org/10.1007/s40710-018-0297-4.

Agency for Toxic Substance and Disease Registry (ATSDR) (2012). *Toxicological profile for manganese*. Atlanta GA: US. Department of Public Health and Human Services.

Agraz-Hernández, C.M., Chan-Keb, C.A., Chávez-Barrera, J., Osti-Sáenz, J., Expósito-Díaz, G., Alonso-Campos, V.A., MuñizSalazar, R., Ruiz-Fernández, A.C., Pérez-Bernal, L.H., Sánchez-Cabeza, J.A., *et al.* (2020). Reserva de Carbón en un Ecosistema de Manglar al Norte de México: Cambios Ambientales Durante 35 Años [Carbon Storage in a Mangrove Ecosystem in Northern Mexico: Environmental Changes Over 35 Years]. Rev. *Mex. Biodiv*., 91, 912910. https://doi.org/10.22201/ib.20078706e.2020.91.2910

Aguirre-Sánchez, J. R., Quiñones, B., Ortiz-Muñoz, J. A., Prieto-Alvarado, R., VegaLópez, I. F., & Martínez-Urtaza, J. (2023). Comparative genomic analyses of virulence and antimicrobial resistance in *Citrobacter* werkmanii, an emerging opportunistic pathogen. *Microorganisms*, 11, 1–17. https://doi.org/10.3390/microorganisms11082114

Aigberua, A. Y. O. B. A. M. I., & Moslen, M. I. E. B. A. K. A. (2017). Space and time dynamics of surface water quality of an Estuarine Creek in The Niger Delta in Nigeria. *Current Studies in Comparative Education, Science and Technology*, *4*(1), 141-155.

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

Alarfaj, A.A., Arshad, M., Sholkamy, E.N., & Munusamy, M.A. (2015). Extraction and characterization of polyhydroxybutyrates (PHB) from *Bacillus* thuringiensis KSADL127 Isolated from mangrove environments of Saudi Arabia. *Brazilian Archives of Biology and Technology*, 58, 781 – 788.

Amadi, A.N., Olasehinde, P.I., Okosun, E.A., & Yisa, J. (2010). Assessment of the Water Quality Index of Otamiri and Oramiriukwa Rivers. *Phys. Int*., 1, 116-123. https://doi.org/10.3844/pisp.2010.116.123

Amarachi, C., John U., & Ejikeme, U. (2023). Assessment of the Physicochemical Characteristics and Water Quality Index of Nkisa River in the Niger Delta, Nigeria. *International Journal of Novel Research in Engineering and Science*, 10(2), 95 – 105. https://doi.org/10.5281/zenodo.10706546

Ameen, F., Moslem, M. Hadi, S., & Al-Sabri, A.E. (2016). Biodegradation of diesel fuel hydrocarbons by mangrove fungi from Red Sea Coast of Saudi Arabia. *Saudi Journal of Biological Sciences*, 23, 211 – 218. https://doi.org/10.1016/j.sjbs.2015.04.005

Anake, W.U., Benson, N.U., Akinsiku, A.A., Ehi-Eromosele, C.O., & Adeniyi, I.O. (2014). Assessment of trace metals in drinking water and groundwater sources in Ota, Nigeria. *International Journal of Scientific and Research Publications*, 4(5), 201 – 214.

Ankley, G., Cureton, P., Hoke, R., Houde, M., Kumar, A., Kurias, J., & Valsecchi, S. (2020). Assessing the ecological risks of per- and polyfluoroalkyl substances: current state-of-the science and a proposed path forward. *Environmental Toxicology and Chemistry*, 40(3), 564 – 605. https://doi.org/10.1002/etc.4869

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

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). (1998). *Standard Methods for the Examination of Water and Waste Water*. 20th Edition, American Waterworks Association, Wash ington DC.

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.

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.

@The Author(s). 2025. Published by CBIORE

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

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

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

Barbier, E.B. (2016). The protective service of mangrove ecosystems: A review of valuation methods, *Marine Pollution Bulletin*, http://dx.doi.org/10.1016/j.marpolbul.2016.01.033

Behera, B.C., Mishra, R.R., Patra, J.K., Dutta, S.K., & Thatoi, H.N. (2008). Physico-Chemical Properties of Water Sample Collected From Mangrove Ecosystem of Mahanadi River Delta, Odisha. *India American Journal of Marine Science*, 2(1), 19-24.

Bibi, F., Ullah, I., Alvi, S., Bakhsh, S., Yasir, M., Al-Ghamdi, A., & Azhar, E. (2017). Isolation, diversity, and biotechnological potential of rhizo- and endophytic bacteria associated with mangrove plants from Saudi Arabia. *Genetics and Molecular Research*, 16, 1 – 12.

Brima, E.I. (2017). Physicochemical properties and the concentration of anions, major and trace elements in groundwater, treated drinking water and bottled drinking water in Najran area, KSA. *Appl Water Sci*., 7, 401–410. https://doi.org/10.1007/s13201-014-0255-x.

Cappello, S., Russo, D., Santisi, S., & Calogero, R. (2012). Presence of hydrocarbon-degrading bacteria in the gills of mussel Mytilus galloprovincialis in a contaminated environment: A mesoscale simulation study. *Chemistry Ecology*, 28(3), 239–252. https://doi.org/10.1080/02757540.2011.639768

Casas-Martínez, M. R., Rodríguez-Rubio, H. A., Bonilla-Suastegui, A., LópezRodríguez, R., Serrano-Rubio, A., & Montes-Aguilar, O. J. (2023). *Citrobacter* koseri: A rare cause of an epidural spinal abscess. Surg. *Neurol. Int*., 14, 7–23. https://doi.org/10.25259/SNI-147-2023

Chahuan, R., & Ramanathan, A.L. (2008). Evaluation of water quality of Bhitarakaika mangrove ecosystem, Orissa, East coast of India. *Indian Journal of Marine Science*, 37, 153-158.

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

Cong'En, J. H., Miah, M., Sünkel-Laing, B., & Emmanuel, J. (2014). Endogenous endophthalmitis caused by *Citrobacter* koseri originating from a renal abscess. *BMJ Case Rep*., 1–5. https://doi.org/10.1136/bcr-2014-204095

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

Donato, D.C., Kauffman, J.B., Murdiyarso, D., Kurnianto, S., Stidham, M., & Kanninen, M. (2011). Mangroves among the most carbon-rich forests in the tropics. *Nature Geoscience*, 4, 293 – 299. https://doi.org/10.1038/NGEO1123

Doughari, J.H., Elmahmood, A.M., & Manzara, S. (2007). Studies on the antibacterial activity of root extracts of Carica papaya L. *African Journal of Microbiology Research*, 37–41

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

Dziri, R., Kuşkucu, M. A., Arfaoui, A., Fethi, M., Ifaoui, S., & Bellaaj, R. (2022). Whole genome sequencing of a *Citrobacter* freundii strain isolated from the hospital environment: an extremely multiresistant NDM-1 and VIM-48 coproducing isolate. *Microb. Drug Resist*., 28, 18–22. https://doi.org/10.1089/mdr.2020.0417

Edema, N.E. (2012). *Effects of crude oil contaminated water on the environment, crude oil emulsions-composition stability and characterization*. Maner El-Sayed Abdul-Raouf (Ed). ISBN: 978-95351-02205.

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 Science*s. 2 (4), 195 – 210. https://doi.org/10.31586/rjees.2022.365

Emery, A., Marpaux, N., Naegelen, C., Valot, B., Morel, P., & Hocquet, D. (2020). Genotypic study of *Citrobacter* koseri, an emergent platelet contaminant since 2012 in France. *Transfusion* 60, 245–249. https://doi.org/10.1111/trf.15617

Erbasan, F. (2018). Brain abscess caused by *Micrococcus* luteus in a patient with systemic lupus erythematosus: Case-Based Review. *Rheumatol. Int*., 38(12), 2323–2328. https://doi.org/10.1007/s00296-018-4182-2

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

Gijo, A.H., Hart, A.I., & Seiyaboh, E.I. (2016). The impact of makeshift oil Refineries on the macro-invertebrates of the Nun River estuary, Niger Delta, Nigeria. *Greener Journal of Biological Sciences* 6(6), 112–119. https://doi.org/10.15580/gjbs.2016.6.121616215.

Giri, C. Ochieng, E. Tieszen, L.L. Zhu, Z. Singh, A. Loveland, T., & Duke, N. (2011). Status and distribution of mangrove forests of the world using earth observation satellite data. *Global Ecology and Biogeography*, 20, 154 – 159. https://doi.org/10.1111/j.1466-8238.2010.00584.x

Gołaś, I., Szmyt, M., & Potorski, J. (2019). Distribution of *Pseudomonas* fluorescens and Aeromonas hydrophila bacteria in a recirculating aquaculture system during farming of European grayling (Thymallus thymallus L.) Broodstock. *Water* 11(2), 376. https://doi.org/10.3390/w11020376

Gupta, S.K., & Gupta, I.C. (2015). *Management of saline and waste water in agriculture*. Scientific Publishers. 2, 1 – 41.

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* (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

Hashimoto, M., Mogi, K., Sakurai, M., Sakata, T., Tani, K., & Takahara, Y. (2021). Rupture of a dissecting thoracoabdominal aortic aneurysm due to *Citrobacter* freundii infection. *Clin. Case Rep*., 9, 1–5. https://doi.org/10.1002/ccr3.4719

Heljanko, V., Johansson, V., Räisänen, K., Anttila, V. J., Lyytikäinen, O., & Jalava, J. (2023). Genomic epidemiology of nosocomial carbapenemase-producing *Citrobacter* freundii in sewerage systems in the Helsinki metropolitan area. *Finland. Front. Microbiol*., 14. https://doi.org/10.3389/fmicb.2023.1165751

Hewitt, M. K., Klowak, J. A., Pernica, J. M., & Leung, J. (2021). *Citrobacter* koseri meningitis and septicemia in a neonate with borderline fever at home. *CMAJ*, 193, E1592–E1594. https://doi.org/10.1503/cmaj.210285

Hoko. (2008). An assessment of the water quality of drinking water in rural district in Zimbabwe. The case of Gokwe south, Nkayi, lupane, and Mwenezi districts. *Phycs. Chem. Earth*, 33, 859-866.

Hölzel, C.S., Tetens, J.L., & Schwaiger, K. (2018). Unraveling the Role of Vegetables in Spreading Antimicrobial-Resistant Bacteria: A Need for Quantitative Risk Assessment. *Foodborne Pathog Dis*., 15(11), 671 – 688.

Hossain, M. & Nuruddin, A. (2016). Soil and Mangrove: A review Journal of Environmental Science and Technology, 9, 198 – 207.

Howladar, M.F., Chakma, E., Koley, N.J., Islam, S., Al-Numanbakth, M.A., Ahmed, Z., & Akter, S. (2021). The water quality and pollution sources assessment of Surma river, Bangladesh using, hydrochemical, multivariate statistical and water quality index methods. *Groundwater for sustainable developent*. 12, 100523

Huxham, M., Emerton, L., Kairo, J., Munyi, F., Abdirizak, H., Muriuki, T., Nunan, F., & Briers, R.A. (2015). Applying climate compatible development and economic valuation to coastal management: a case study of Kenya's mangrove forests. *Journal of Environmental Management*, 157, 168–181.

Ianniello, N.M., Andrade, D.C., Ivancic, S., Eckardt, P.A., & Ramirez, L.J.C. (2019). Native valve infective endocarditis due to *Micrococcus* luteus in a non-Hodgkin's lymphoma patient. *IDCases*. 18, e00657. https://doi.org/10.1016/j.idcr.2019.e00657

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

Iorwua, M., Onyebuchi, M., Tiza, M., & Iorwua, J. (2018). Physico-Chemical Analysis of Some Wells and Streams in North Bank, Makurdi-Benue State, Nigeria. *International Journal for Research in Engineering Application and Management*, 4, 84-89.

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. https://doi.org/10.1080/1010.6049.2018.1489423

James, G.K., Adegoke, J.O., Osagie, S., Ekechukwu, S., Nwilo, P., & Akinyede, J. (2013). Social valuation of mangroves in the Niger Delta region of Nigeria. *International Journal of Biodiversity Science, Ecosystem Services and Management*, 9 (4), 311–323. https://doi.org/10.1080/21513732.2013.842611

Jiménez, A., Castro, J. G., Munoz-Price, L. S., De Pascale, D., Shimose, L., & Mustapha, M. M. (2017). Outbreak of Klebsiella pneumoniae Carbapenemase-Producing *Citrobacter* freundii at a Tertiary Acute Care Facility in Miami, Florida. *Infect. Control Hosp. Epidemiol*. 38, 320–326. https://doi.org/10.1017/ice.2016.273

Kadafa, B. Ayuba, A. (2012). Environmental impacts of oil exploration and exploitation in the Niger Delta of Nigeria, *International Research Journal Publisher: Global Journals Inc* 12.

Karavoltsos, S., Sakellari, A., Mihopoulos, N., Dassenakis, M., & Scoullos, M.J. (2008). Evaluation of the quality of drinking water in regions of Greece. *Desalination* 224 (1–3), 317–329, https://doi.org/10.1016/j.desal.2007.06.013.

Kathiresan, K. (2001). *Ecology and Environment of Mangrove Ecosystems. Centre of Advanced Study in Marine Biology*, Annamalai University, pp: 106107.

Kerr, K.G., & Snelling, A.M. (2009). *Pseudomonas* aeruginosa: a formidable and everpresent adversary. *J Hosp Infect*, 73(4), 338 – 344.

Kim, K., Seo, E., Chang, S.K., Park, T.J., & Lee S.J. (2016). Novel water filtration of saline water in the outermost layer of mangrove roots. *Scientific Reports*, 6, 1 – 10. https://doi.org/10.1038/srep.20426

Licata, G., De-Rosa, A., Gambardella, A., Calabrese, G., Argenziano, G., Della & Rocca, M. T. (2021). Bullous Erysipelas caused by *Citrobacter* koseri. *J. Clin. Aesthet. Dermatol*. 14, 12.

Löffler, P., Escher, B., Baduel, C., Virta, M., & Lai, F. (2023). Antimicrobial transformation products in the aquatic environment: global occurrence, ecotoxicological risks, and potential of antibiotic resistance. *Environmental Science & Technology*, 57(26), 9474–9494. https://doi.org/10.1021/acs.est. 2c09854

Mahvi, A.H., & Razazi, M. (2005). Application of polyelectrolyte in turbidity removal from surface water. *American Journal of Applied Science*, 2, 397-399. https://doi.org/10.3844/ajassp.2005.397.39 9

Mariappan, N.A., Kanmani, T., & Parthiban, S. (2016). A study of water quality status of mangrove vegetation in Pichavaram estuary. *Journal of Agriculture and Ecology Research International*, 5(3), 1-11.

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 Year 2013, 1(2), 141-156.

Mojiri. A., Zhou, J.L., Ohashi, A., Ozaki, N., & Kindaichi, T. (2019). Comprehensive review of polycyclic aromatic hydrocarbons in water sources, their effects, and treatments. *Sci Total Environ*., https://doi.org/10.1016/j.scitotenv.2019.133971.

Moslen, M., & Daka, E.R. (2016) Spatio-temporal differences of physico-chemical variables in relation to industrial effluent discharges into Ekerekana and Okochiri creeks, Bonny estuary of the Niger Delta, Nigeria, *Journal of Nigerian Environmental Society* (JNES) 2 (10), 263 – 67.

Moussa, S., Mamadou, G., Binta, G., Mamoudou, D., Yannick, M. N., Alimata, K., *et al*. (2023). *Citrobacter* freundii skin infection in an immunocompetent subject simulating varicella: A treatment-resistant case article information. *Dermatology*, 8, 1–3. https://doi.org/10.17140/DRMTOJ-8-152

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

Mulcahy, L.R., Isabella, V.M., & Lewis, K. (2014). *Pseudomonas* aeruginosa biofilms in disease. *Microb Ecol*., 68(1), 1 – 12.

Nair, G., Lakshminarayana, M., Nagaraj, L., Kumar, M. N., & Thilak, S. A. (2020). Urinary infections and *Citrobacter*: An unpleasant scenario. *Int. J. Adv. Community Med.* 3, 249–253. https://doi.org/10.33545/comed.2020.v3.i1d.217

National Center for Emerging and Zoonotic Infectious Diseases (NCEZID) (2024). *United States, the Centers for Disease Control and Prevention (CDC)*.

Nguyen, A.T., & Tallent, S.M. (2019). Screening food for *Bacillus* cereus toxins using whole genome sequencing. *Food Microbiol*., 78, 164 – 170.

Ogamba, E.N., Chinda, A.C., Ekweozor, I.K.E., & Onwuteaka, J.N. (2004). Water quality and phytoplankton distribution in Elechi Creek complex of the Niger Delta. *Journal of Nigerian Environmental Society*, 1 (2), 121–130.

Ogbeibu, A.E., & Anagboso, M.U. (2004). Baseline Limnological Investigation of the Utor River in Esan South-East, Edo State, Southern Nigeria: 1. Physical and Chemical Hydrology. *Tropical Freshwater Biology*, 12, 45-62 .

Ojekunle, O.Z. *et al*., (2016). 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.

Olalekan, R. M. Omidiji, A. O., Nimisngha, D., Odipe O. E. & Olalekan, A. S. (2018). Health Risk Assessment on Heavy Metals Ingestion through Groundwater Drinking Pathway for Residents in an Oil and Gas Producing Area of Rivers State, Nigeria. *Open Journal of Yangtze Gas and Oil*, 3, 191 – 206. https://doi.org/10.4236/ojogas.2018.

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. *OpenAccess Library Journal*, 8(9),1 – 17.

Oparaocha, E.T., Iroegbu, O.C., & Obi, R.K. (2010). Assessment of quality of drinking water sources in the Federal University of Technology, Owerri, Imo State, Nigeria. *Journal of Applied Bioscience*, 32, 1964–7196.

Orewale, M.O., Mkainde, O.W., & Adekuleu-Kand, K.A. (2007). Chemical Examination of piped water supply of Ile – Ife in south west Nigeria, *Iranian Journal of Environment, Health Sciences and Engineering*, 4(1), 51-56.

Oyeleke, B. & Manga, S.B. (2008). *Essential of Laboratory Practical in Microbiology* Department of Microbiology, UDUS. 20, 36-65.

Petronella, G.A.T., Yusoff, M.K., Majid, N.M., Joo, G.K., & Huang, G.H. (2009). Effect of N and K fertilizers on nutrient leaching and groundwater quality under mature oil palm in sabah during the monsoon period. *American Journal of Applied Sciences*, 6, 1788-1799. https://doi.org/10.3844/ajassp.2009.1788.1799

Prabu, V.A., Rajkumar, M., & Perumal, P. (2008). Seasonal variations in physico-chemical characteristics of Pichavaram mangroves, Southeast coast of India. *Journal of Environmental Biology*, 29(6), 945-950.

Punmia, B.C., Arun, K.J., & Ashok, K.J. (2007). *Waste Water Engineering Including Air Pollution*. Environmental Engineering 2. Daryaganji, New Delhi.

Puyate, Y., & Rim-Rukeh, A. (2010). Some physico-chemical and biological characteristics of soil and water samples of part of the Niger Delta area, Nigeria. *J. Appl. Sci. Environ. Manag*. 12 (2), https://doi.org/10.4314/jasem.v12i2.55551.

Qin, S., Xiao, W., & Zhou, C., (2022) *Pseudomonas* aeruginosa: pathogenesis, virulence factors, antibiotic resistance, interaction with host, technology advances and emerging therapeutics. *Signal Transduct Target Ther*., 7(1), 199. https://doi.org/10.1038/s41392-022-01056-1

Rachel, H., McDowell, Evan, M., & Friedman, H. (2023). *Bacillus* Cereus, NCBI Bookshelf. A service of the National Library of Medicine, National Institutes of Health. StatPearls [Internet]. Treasure Island (FL): StatPearls Publishing.

Ramirez, D., & Giron, M. (2023). *Enterobacter* Infections. NCBI Bookshelf. A service of the National Library of Medicine, National Institutes of Health. StatPearls. Treasure Island (FL): StatPearls Publishing; 2024.

Rogers, K. (2024). *Enterobacter* bacteria genus Encyclopaedia Britannica Article History

Rosli, N., Gandaseca, S., Ismail, J., & Jailan, M.I. (2010). Comparative study of water quality at different peat swamp forest of Batang Igan Sibu Sarawak. *American Journal of Environmental Sciences*, 6, 416-421. https://doi.org/103844/ajessp.2010.416-421

Rostamzad, A., Abozar, A. C. K., Omidi, M., & Hatamnia, A. A. (2019). Antibiotic resistance of *Citrobacter* freundii in clinical isolates: A systematic review and metaanalysis. *J. Basic Res. Med. Sci*., 6, 58–63.

Saalidong, B.M., Aram, S.A., Otu, S., & Lartey, P. O. (2022). Examining the dynamics of the relationship between water pH and other water quality parameters in ground and surface water systems, *PLoS ONE* 17(1), 0262117. https://doi.org/ 10.1371/journal.pone.0262117.

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

Seca, G., Noraini, R., Johin, N., & Chandra, I.A. (2011). Status of Water Quality Based on the Physico-Chemical Assessment on River Water at Wildlife Sanctuary Sibuti Mangrove Forest, Miri Sarawak. *American Journal of Environmental Sciences* 7 (3), 269-275.

Sengupta, P. (2013). Potential Health Impacts of Hardwater. *International Journal of Preventive Medicine*, 4, 886-875.

Shigut, D.A., Liknew, G., Irge, D.D., & Ahmad, T. (2017). Assessment of physicochemical quality of borehole and spring water sources supplied to Robe Town, Oromia Region, Ethiopia. *Appl Water Sci*., 7:155–64. https://doi.org/10.1007/s13201-016-0502-4.

Sohaib, M., Al-Barakah, F.N., Migdadi, H.M., & Husain, F.M. (2022a). Comparative study among Avicennia marina, Phragmites australis, and Moringa oleifera based ethanolic-extracts for their antimicrobial, antioxidant, and cytotoxic activities. *Saudi Journal of Biological Sciences*, 29(1), 111 – 122. https://doi.org/10.1016./j.sjbs.2021.08.062

Sohaib, M., Al-Barakah, F.N., Migdadi, H.M., Husain, F.M. & Alyousif M. (2022b). Isolation and abundance of different culturable microbes from mangrove environments in coastal areas of Saudi Arabia. *International Journal of Current Microbiology and Applied Sciences*, 11(4), 215 – 238. https://doi.org/10.20546./ijcmas.2022.1104.030

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

@The Author(s). 2025. Published by CBIORE

Srilatha, G., Thilagavathi, B., & Varadharajan, D. (2012). Studies on the physico-chemical status of Muthupettai mangrove, south east coast of India. *Advances in Applied Science Research*, 3(1), 201-20

Srilatha, G., Varadarajan, D., Chamundeswari, K., & Mayavu, P. (2013). Study on physicochemical parameters in different mangrove regions, Southeast Coast of India. *Journal of Environmental And analytical Toxicology*, 3(5), 2-8.

Srinivasan, V., Natesan, U., & Parthasarathy, A. (2013). Seasonal variability of coastal water quality in bay of Bengal and Palk strait, Tamilnadu, southeast coast of India. *Brazilian Archives of Biology and Technology*, 56(5), 875-884.

Subba N., Rao, *et al.,* (2017). Geochemical characteristics and controlling factors of chemical composition of groundwater in a part of Guntur district. Andhra Pradesh, India. *Environ. Earth Sci*. 76 (21), 7093 – 8. https://doi.org/10.1007/s12665-017-7093-8.

Suthar, S., Bishnoi, P., Singh, S., Mutiyar, P.K., Mema, A.K., & Patil, N.S. (2009). Nitrate contamination in groundwater of some rural areas of Rajasthan, India. Hazard. *Water*, 171, 189-199.

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

UN (2016). *United Nations General Assembly declares access to clean water and sanitation is a human right*. UN News Centre.

UN GEMS/Water (2005). *Suspended solids and water quality. National Water Research Institute Burlington*. http://www.gemswater.org/atlasgwq.solids-e.html

United Nations General Assembly Resolution (UNSD). (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. A/RES/70/1.

United States Environmental Protection Agency (USEPA) (2012), *Drinking water standards and health advisories*. Office of Water, USEPA, Washington, D.C., EPA 822-S-12-001.

Urbinati, F., Rocha-de-Lossada, C., García-Montesinos, J., García-Lorente, M., Borroni, D., & Pardo-Ruiz, R., (2023). *Citrobacter* koseri as emergent microorganism in infectious keratitis. *J. Fr. Ophtalmol*., 46, e30–e33. https://doi.org/10.1016/J.JFO.2022.06.011

USEPA (2004). *Risk Assessment Guidance for Superfund Volume I: Human Health Evaluation Manual (Part E, Supplemental Guidance for Dermal Risk Assessment)*. USEPA: Washington, DC, USA.

USEPA (US Environmental Protection Agency) (2009). *Water: Drinking water contaminants*. US EPA 816-F-09-0004. http:// water.epa.gov/drink/contaminants/index.cfm#two.

Usman, A.R., Alkredaa, R.S., & Al-Wabel, M. (2013). Heavy metal contamination in sediments and mangroves from the coast of Red Sea: Avicennia marina as potential metal bioaccumulator. *Ecotoxicology and Environmental Safety*, 97, 263 – 270.

Van Bochove, J., Sullivan, E., & Nakamura, T. (2014). *The importance of mangroves to people: A call to action*. United Nations Environment Programme.

Vilas, M.A., & Ashwinova, G. (2015). Water and soil quality analysis of selected areas of Sunderban and mapping using GIS technique. *International Journal of Research in Chemistry And Environment*, 5(4), 44-59.

Wang, D.H., Wang, Y., & Lin, Z. (2007). The control and damage of organic pollutant in Songhua River to the ecological environment. *Environmental Science Management*, 32(6), 67-69.

Wang, Q., & Yang, Z. (2016). Industrial water pollution, water environment treatment, and health risks in China. *Environ. Pollut*, 218, 358–365. https://doi.org/10.1016/J.ENVPOL.2016.07.011.

Waziri, M., & Ogugbuaja, V.O. (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 Organization (2020) *Guidelines for Drinking Water Quality*. Geneva.

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) 2001. *Arsenic and arsenic compounds, Environmental Health Criteria volume 224*. WHO: Geneva.

World Health Organization (WHO). (2011). *Guidelines for Drinking-Water Quality Fourth 565 edition*. WHO Library Cataloguing-in-Publication: Switzerland.

@The Author(s). 2025. Published by CBIORE

Wright, K.F. (2015). Is your drinking water acidic? A comparison of the varied pH of popular bottled waters, *J. Dent. Hyg*., 89, 6–12.

Yisa, J. & Jimoh, T. (2010). Analytical studies on water quality index of River Landzu. *American Journal of Applied Science*, 7, 453-458. https://doi.org/10.3844/ajassp.2010.453.458

Zabbey, N., & Arimoro, F.O. (2017). Environmental forcing of intertidal benthic macrofauna of Bodo Creek, Nigeria: preliminary index to evaluate cleanup of Ogoniland. *Reg Stud Mar Sci*, 16, 89–97.

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. https://doi.org/:10.1016/b978-0-12-805052-1.00024

@The Author(s). 2025. Published by CBIORE