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Determination of Physicochemical Properties of River Sediment and Heavy Metal Content from River Benue in Ibi, Taraba State

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Abstract

This study assessed contamination levels, potential ecological risks, and pollutant sources of five heavy metals (HMs) in sediments of the River Benue within Ibi Local Government Area, Taraba State, Nigeria. Sediment samples were collected and analyzed for physicochemical properties and trace metal concentrations, including total hydrocarbon content (THC), cadmium (Cd), nickel (Ni), lead (Pb), and zinc (Zn). The results showed that the mean concentrations of the analyzed heavy metals and THC were below the permissible limits established by Nigerian regulatory standards. Similarly, physicochemical parameters—such as pH, electrical conductivity (EC), nitrate, total hydrogen content, sulphate, phosphate, and temperature—were within acceptable environmental limits. Pollution assessment indices, including the Enrichment Factor (EF), Pollution Load Index (PLI), and Geo-accumulation Index (Igeo), indicated low contamination levels, with values generally falling within World Health Organization (WHO) guidelines. Despite these low levels, the study suggests that anthropogenic activities in the region, such as agriculture, domestic discharge, and informal mining, may contribute to the presence of toxic substances in the sediments. The study warns that prolonged exposure to untreated water from this site poses potential health risks. Therefore, continuous environmental monitoring and pollution mitigation strategies are recommended to prevent future ecological degradation and associated public health concerns.

Keywords: River Benue; Heavy Metals; Sediment Contamination; Ecological Risk; Anthropogenic Pollution; Environmental Monitoring

INTRODUCTION

Sediments in aquatic environments function as critical repositories for heavy metals (HMs), acting as both sinks and sources of these pollutants. Their capacity to retain and transport toxic metals makes them essential indicators of environmental contamination. According to Garvunga et al. (2019), sediments play a pivotal role in the long-term storage and mobility of hazardous substances, particularly in riverine and coastal systems. Identifying the origins and pathways of heavy metals is therefore fundamental to environmental monitoring and remediation strategies (Mariusz & Jaskula, 2022).

Heavy metals possess the ability to bioaccumulate in living organisms, including humans, animals, plants, and microorganisms. This bioaccumulation can lead to toxic effects, especially when sediment concentrations are elevated, often correlating with deteriorating water quality (Singovszka & Baluintova, 2019). Sediment particles readily absorb and integrate various pollutants through ion exchange and adsorption processes. These include not only heavy metals but also organometallic compounds, polycyclic aromatic hydrocarbons (PAHs), petroleum derivatives, lubricants, and industrial additives such as anti-corrosion and antifreeze agents. Such pollutants can significantly alter the chemical composition of water bodies and pose serious threats to aquatic ecosystems (Udongwo, 2025).

Industrialization and agricultural expansion have intensified the release of heavy metals into aquatic systems, resulting in widespread contamination. These metals—such as lead (Pb), cadmium (Cd), manganese (Mn), nickel (Ni), and zinc (Zn)are frequently discharged into rivers, causing sub-lethal effects or mortality in aquatic organisms. Sediment disturbance, whether natural or anthropogenic, can reintroduce these pollutants into the water column, exacerbating ecological damage. Benthic sediments not only influence water chemistry but also serve as habitats and food sources for bottom-dwelling fauna, which are particularly vulnerable to toxic exposure (Azrina et al., 2011).

The impact of sediment contamination extends beyond aquatic environments. Through bioaccumulation and biomagnification, heavy metals can infiltrate terrestrial food webs, ultimately affecting human health. Sediment contaminants are broadly categorized into inorganic substances (primarily heavy metals), organic compounds, microorganisms, and chemical disinfectants (Nollet, 2006). Inorganic pollutants dominate sediment profiles, with heavy metals being especially concerned due to their persistence and toxicity. These metals are non-biodegradable and can accumulate in human tissues, disrupting neurological, renal, and cardiovascular functions (WHO, 2011; Giuseppe et al., 2020).

Lead (Pb) is known to impair cognitive and physical development in infants, while excessive exposure to zinc (Zn) and manganese (Mn) may cause gastrointestinal distress, headaches, and appetite loss (Raman, 2020). Cadmium (Cd) and nickel (Ni) have been epidemiologically linked to cancer, kidney dysfunction, and neurodegenerative disorders. The U.S. Environmental Protection Agency (USEPA, 2015) emphasizes that even trace concentrations of these metals can pose significant health risks due to their high density and toxicity.

To assess sediment contamination, researchers employ a range of analytical techniques, including measurements of pH, temperature, electrical conductivity, total organic carbon, pollution load index, and concentrations of heavy metals. These parameters influence water quality and the viability of aquatic habitats (Ashish et al., 2019). Sediments are sourced from diverse environments—rivers, lakes, oceans, springs, and even rainfall—and are impacted by anthropogenic activities such as industrial discharge, agricultural runoff, and urban development (Aremu et al., 2010).

The River Benue, Nigeria's second-largest river, exemplifies a dynamic aquatic system vulnerable to heavy metal pollution. Originating from the Adamawa Plateau in Cameroon, it traverses key Nigerian towns including Jimeta, Ibi, Wukari, and Makurdi before merging with the River Niger at Lokoja. The river supports extensive agricultural, mining, and transportation activities, all of which contribute to sediment contamination. Sequential extraction techniques, such as the optimized BCR method, are employed to isolate metal fractions in sediments, providing insights into their bioavailability and ecological risk.

Ibi and Chinkai, located along the Benue River in Taraba State, Nigeria, are particularly susceptible to sediment pollution due to their proximity to tributaries and mineral-rich soils. These regions, situated within the Guinea Savannah, support diverse agricultural and fishing activities. The presence of mineral deposits, including lead and zinc, further underscores the need for rigorous environmental assessment and sustainable land-use practices.

Statement of problem

Studies have shown that anthropogenic inputs may increase heavy metal concentration in sediments, benthic region, crops, aquatic products and human system (Perumal et al., 2021).

Aquatic life is directly and indirectly affected by pollutants present in sediments, and they can be distributed across trophic levels. This pollutant causes adverse effects on aquatic life and human health.

Rivers are generally a common medium for the transport and distribution of various contaminants and pollutants including heavy metals. Moreover, they are an important source of water for domestic and agricultural purposes. Therefore, it is necessary for rivers to be assessed periodically to guarantee the safety of their usage.

It is because of this that the physicochemical properties and some heavy metal concentration in sediment samples from the River Benue in Ibi LGA of Taraba State were examined.

Justification

River sediments can serve as sink for different pollutants especially heavy metals (Astatkie, 2021).

Heavy metals are a serious environmental issue due to its bioaccumulating factor in organ and tissues (Neseri et al., 2021).

Therefore, physicochemical analysis was carried out on sediment samples taken from River Benue in Ibi LGA, Taraba state, Nigeria, to assess the extent of pollution.

Aim and Objective

Aim

This study was aimed at determining the physio-chemical properties and some heavy metal content of sediments from River Benue in Ibi LGA, Taraba State Nigeria.

Objectives

The objectives of this study include:

•To determine physio-chemicals properties of the sediment samples from River Benue in Ibi LGA, Taraba State Nigeria.

•To determine concentration of Heavy Metals (Pb, Ni, Zn, Cd, and Mn) in Sediment samples from River Benue in Ibi LGA, Taraba State Nigeria.

•To determine the pollution load index (PLI) of sediment sample from River Benue in Ibi LGA, Taraba State Nigeria.

•To determine the enrichment factor (EF) of sediment sample from River Benue in Ibi LGA, Taraba State Nigeria.

•To determine the Geo-Accumulation index of sediment sample from River Benue in Ibi LGA, Taraba State Nigeria.

Sediment

Sediment is a solid material that is moved and deposited in a new location. Sediment consists of rocks and minerals, as well as the remains of plants and animals. It can be small as a grain or as large as a boulder. Sediment moves from one place to another through the process of erosion. Erosion is the removal and transportation of rocks or soil. Erosion can move sediment through water, ice or wind. Water can wash sediment, such as gravel or pebbles, down from a creek, into a river, and eventually to that river delta. Delta, riverbanks and the bottom of waterfalls are common areas where sediment accumulates. Glaciers can freeze sediment and then deposit it elsewhere as the ice carves its way through the landscape or melts. This sediment created is known as moraine. Wind can move dirt across a plain in dust storms or sandstorms. Sand dunes are made of rocky sediment worn down by wind and collision with other sand particles (Jeannie *et al*., 2022).

Sediment quality

Sediment quality is assessed by comparing measured results to historical, pre-development, and regional baseline values to identify any changes that have occurred and to identify stations with sediment quality is outside the range of natural variability. The relationship between sediment quality and benthic invertebrate measurement endpoints is assessed using statistical correlation analysis to identify those habitat features that consistently affect benthic invertebrate community composition (Lockhart *et al.*, 2006).

Physio-chemical Parameters

Physio-Chemical parameters of sediment indicate the safety of river sediment (Macdonald and Kay, 2015) and their analysis is important for public health and pollution studies (Kot *et al.,* 2000).

Total Hydrocarbon content, pH, sulphate, nitrate, phosphate, electrical conductivity, temperature are the most important Physio-chemical properties of sediment in relation to its quality.

Sulphate

Sulphate is an inorganic salt of sulfuric acid, soluble in water. In the deep ocean sulfate penetrates deeply into sediments because of the low supply of reduced organic matter. In contrast, sulphate is rapidly depleted in ocean sediments with high organic inputs.

pH

pH is the negative logarithm of H^+ ion concentration. pH of water ranges from 0 to 14. pH value of 7 to 14 is alkaline in nature while the pH value 0 to 7 is acidic and pH value 7 is neutral. The acidity of groundwater is due to the presence of organic acids in the soil as well as those of atmospheric origin infiltrated to the water (Chapman and Kimstach, 2017). High pH levels make water become less corrosive (Gustafsson, 2003). The pH value is measured using pH meter.

Total hydrocarbon content (THC)

THC it's used to describe the quantity of the measured hydrocarbon impurities present. Total hydrocarbon content values range between 0.001 to 1.43mg/kg.

Electrical conductivity (EC)

EC is the capacity of sediment to carry an electrical current and the electrical conductivity depends upon concentration of sediment, type of ions, number of ions & their mobility. E.C. measured by E.C. meter.

Phosphate

Total phosphate in soil ranges from 150 to 700ug P/g. Soil from very old landmasses, often contains low phosphate content (Neal 2009).

Nitrate

Nitrate level underground is actually very low (less than 10mg/1NO3)|, but nitrate concentration grows due to man's activities.

Temperature

Sediment reduces the amount of light penetrating the water, depriving the plants and aquatic habitat of needed light for their activities. Sediment absorbs the hotness of th c e sun and thus increases the water temperature, (Mari 2016).

Heavy metals

The term "heavy metal" refers to any metal and metalloid element that has a relatively high density ranging from 3.5 to 7 g cm^3 and is toxic or poisonous at low concentrations, and includes cadmium (Cd), zinc (Zn), nickel (Ni), manganese (Mn) and lead (Pb). Although heavy metal is a general term defined in literature, it is widely documented and -+frequently applied to the widespread pollutants of soil and water bodies. These metals are found widely in the earth's crust and are non-biodegradable in nature. They enter the human body via air, water and food. A small number have an essential role in the metabolism of humans and animals in very trace amounts, but their higher concentration may cause toxicity and health hazards. (USEPA, 2015). The high concentration of heavy metal intensively has effects on health, number of diseases increases day by day like cancer that are associated with heavy metal (USEPA, 2015). The heavy metals can enter into the environment through anthropogenic activities and natural processes. An industrial process like electroplating, metal smelting and industrial waste are also the sources of heavy metal (Hei *et al.,* 2008). Most of the countries do not properly recycle agricultural waste, industrial wastewater and Industrial waste, so it is also a source of excess heavy metal. (Gupta, 2008, Liu *et al.* 2011, 2012)). Sediments that are below the water adsorb metal and provide a continuous source of toxic water. The industrial process, waste and traffic pollution are the essential source that introduce toxic metals (lead and mercury) into the atmosphere, these metals accumulate in soil and then enter to water gradually by surface runoff due to acid rain (Wang *et al.,* 2015).

Sources of Heavy Metals

Heavy metals differ widely in their chemical properties, and are used extensively in electronics, machines and the artifacts of everyday life, as well as in high-tech applications. As a result, they can enter the aquatic and food chains of humans and animals from a variety of anthropogenic sources as well as from the natural geochemical weathering of soil and rocks. The main sources of contamination include mining waste, landfill leaches, municipal wastewater, urban runoff and industrial wastewater, particularly from the electroplating, electronic and metal-finishing industries. With increasing generation of metals from technology activities, the problem of waste disposal has become one of paramount importance. Many aquatic environments face metal concentrations that exceed water quality criteria designed to protect the environment, animals and humans. The problems are exacerbated because metals have the tendency to be transported with sediments, are persistent in the environment and can bio-accumulate in the food chain. Some of the oldest cases of environmental pollution in the world are due to heavy metal use, for example, Mn, Cd, Zn, Ni and Pb mining, smelting and utilization by ancient civilizations, such as the Romans and the Phoenicians. Heavy metals are among the most common pollutants found in wastewater. These metals pose a toxic threat to human beings and animals even at low concentration.

Heavy Metal and its Effect on Health

Heavy metals contamination in sediment poses a serious threat to human life because of their toxicity, bio-accumulative nature, and persistence in the environment (Rajeshkumar *et al.,* 2018). The heavy metals contaminate the sediment, groundwater and surface water through a natural process and anthropogenic activities (e.g., industrial, agricultural, mining, and traffic activities) (Wongsasuluk *et al.,* 2014. Hashemi *et al.,* 2018). However, safely managed sediment deposit can still be polluted by toxic elements due to the poor domestic treatment system, use of chemical materials in the water treatment system. To date, most of the developing countries are faced with this challenge, usually due to their limited economic capacities to use advanced technologies for heavy metal removal (WHO, 2015).

Some heavy metals are essential for health but in limited concentration, high concentration creates harmful effects on health. Zinc (Zn) and Cadmium (Cd) are important for health but in limited concentration (Solomons and Ruz, 2016), (Singh *et al.,* 2006, Fosmire, 2018).

Therefore, determination of the level of heavy metals in different sediment deposits is important for proper human health risk assessment (EPA, 2012 & WHO, 2013). According to the Environmental Protection Agency (EPA) and Agency for Research on Cancer (IARC), exposure to inorganic arsenic and toxic heavy metals are of major concern in drinking water, mainly due to their carcinogenic and non-carcinogenic effects on human health. Arsenic, Cd, and Cr sediment and water have been pointed to as a public health concern in >30 countries may be the cause of lung, liver, bladder, and kidney cancer (Chowdhury *et al.,*2016, Dawoud & Purucker 2018). Other effects such as anemia from Pb (EPA, 2012), gastrointestinal disorder from Cu (EPA, 2012 and Saha *et al.,* 2017), kidney and liver damage from Zn, and blood cholesterol and heart diseases from Cd were also reported (Saha *et al.,* 2017 and Siuki *et al.,* 2018).

Lead (Pb)

Lead is a toxic heavy metal, and it is found in the earth crust (Raviraja *et al.,* 2008). There are too many sources that introduce lead in atmosphere such as Industrial waste, household paint, and vehicle exhaust (Nadeem-ul-Haq *et al.,* 2009). The permissible limit set by WHO for Lead in sediment is 1.86mg/kg and 1.49mg/kgl during the dry season and rainy season, respectively. Excess amount of lead creates harmful effects on health, and it can directly destroy the major organs and system of the body. Kidney failure, haematopoietic, cardiovascular diseases, nervous disorder, and effect on immunological system, these are the most common diseases due to interaction of lead. (Gidlow 2004, Riess and Halm 2007, Venkatesh 2004). In women during pregnancy, even low concentration of lead can have effect on the newborn baby, low birth weight and miscarriage (Bellinger, 2005; McMichael *et al.,* 2019). In men exposure to high level of lead can damage the organs which produce the sperm.

Cadmium (Cd)

Cadmium exerts toxic effects on kidneys as well as the skeletal and respiratory systems. It is classified as a human carcinogen. It's generally present in the environment at low levels, however human activity has greatly increased levels in environmental media relevant to population exposure (WHO 2022). Cadmium affects cell proliferation, differentiation, and apoptosis. These activities interact with DNA repair mechanism, the generation of reaction oxygen species and the induction of apoptosis, cadmium binds to the mitochondria and inhibit both cellular respiration and oxidative phosphorylation at low concentration (Patrick 2003). Its toxicity involves depletion of reduced glutathione (GSH), binds sulfhydryl groups of protein, and causes to enhance production of reactive oxygen species (ROS) such as superoxide ion, hydrogen peroxide, and hydroxyl radicals. The lowest lethal dose of Cd is 5gr in a 70kg man (Nelson 2011).

Zinc (Zn)

Zinc is an essential trace element and has a few roles and functions in the human body. Its an essential cofactor for more than 300 enzymes involved in the synthesis and metabolism of carbohydrates, lipids, proteins, nucleic acids and other micronutrients, it's needed for the sense of teste and smell and involved in healing and tissue repair, zinc normally accumulates in the acute kidney injury. An average sized adult male has 1.4 to 2.3g of zinc, 60% of the total body zinc content is found in the skeletal muscle and 30% in bone mass. Recommended daily zinc intake for adults is 10-15mg daily. Excess zinc concentration can lead to diarrhea, growth restriction, delayed sexual delay maturation, impotence, alopecia, weight loss, impaired wound healing etc (Lazzerini 2016).

Nickel

Nickel (Ni) metal and Ni compounds are widely used in applications like stainless steel, alloys, and batteries. Nickel is a naturally occurring element in water, soil, air, and living organisms, and is essential to microorganisms and plants. Thus, human and environmental nickel exposures are ubiquitous. Production and use of nickel and its compounds can, however, result in additional exposures to humans and the environment. Notable human health toxicity effects identified from human and/or animal studies include respiratory cancer, non-cancer toxicity effects following inhalation, dermatitis, and reproductive effects. These effects have thresholds, with indirect genotoxic and epigenetic events underlying the threshold mode of action for nickel carcinogenicity. Differences in human toxicity potencies/potentials of different nickel chemical forms are correlated with the bioavailability of the Ni2+ ion at target sites. Likewise, Ni2+ has been demonstrated to be the toxic chemical species in the environment, and models have been developed that account for the influence of abiotic factors on the bioavailability and toxicity of Ni2+ in different habitats. Emerging issues regarding the toxicity of nickel nanoforms and metal mixtures are briefly discussed. This review is unique in its covering of both human and environmental nickel toxicity data (Samuel *et al.*, 2019).

Manganese

Manganese is an essential trace element that is naturally present in many foods and available as a dietary supplement. Manganese is a cofactor for many enzymes, including manganese superoxide dismutase, arginase, and pyruvate carboxylase (Nielson *et al.*, 2012, Buchman *et al.*, 2014). Through the action of these enzymes, manganese is involved in amino acid, cholesterol, glucose, and carbohydrate metabolism; reactive oxygen species scavenging; bone formation; reproduction; and immune response (Li and Yang 2012). Manganese also plays a role in blood clotting and hemostasis in conjunction with vitamin K (Aschner 2005). Manganese is absorbed in the small intestine through an active transport system and, possibly, through diffusion when intakes are high. After absorption, some manganese remains free, but most are bound to transferrin, albumin, and plasma alpha-2-macroglobulin. Manganese is taken up by the liver and other tissues, but the mechanism of this process is not well understood.

The human body contains about 10 to 20 mg manganese, of which 25% to 40% is in bone, (Nielson *et al.*, 2012, Buchman *et al.*, 2014). The liver, pancreas, kidney, and brain also contain manganese. The body maintains stable tissue manganese concentration through regulatory control of manganese absorption and excretion. More than 90% of absorbed manganese is excreted via bile into the feces, and a small amount is re-absorbed, very little is excreted in urine.

Manganese status is difficult to assess and not routinely measured in clinical practice. Normal whole blood concentrations of manganese range from 4 to 15 mcg/L (Nielson et al., 2012, but they are highly variable, and their utility as a status indicator is unclear. Some studies that measured serum or plasma manganese concentrations in apparently healthy adults have shown mean serum concentrations of 1.04 mcg/L and mean plasma concentrations of 1.28 mcg/L (Greger *et al*., 2019). Large variations in manganese intakes appear to affect these concentrations somewhat (Davis and Greger 2016). Although urinary manganese concentrations decrease with severe deficiency.

Sediment Treatment Techniques or Removal of Heavy Metal from sediment.

As we all know, the world is growing fast, and science plays the most important role. Industries are also part of science and Technology. There are so many different technologies use to remove pollutants; each technology has certain advantages and disadvantages. Ion exchange, super critical fluid extraction, adsorption (Lesmana *et al.,* 2009), electro-dialysis, filtration, precipitation (Huang *et al*., 2015), the electrochemical process, microbial system (Ahmed & Ahmaruzzaman,2016), membrane bioreactor and an advanced oxidation process (Hazard, et al*.,* 2014), many techniques are available for removing heavy metal from sediment. They are Classified into three categories: chemical, biological and physical.

Ion Exchange Separation Technique

Ion exchange separation, in which one of an ions is substituted to another ion that is present in the sediment, (Shah *et al.,* 2013). The separation depends on ion exchange resin quality, based on the chemical property. Mainly two types of resins, synthetic and natural resin (Shah *et al.,* 2013). Synthetic resin gives a much better result as compared to natural one. In each type of the resin are further divided into two types, Cation and anion exchange resin. For removal of metal use cation resin. In zeolites the Ion exchange efficiency increases with this alkaline charge balancing cation Na^{+}, K^{+}, Ca^{2+}, Mg^{2+} these ions are connected electro-statically with Al (H. Figueiredo & Quintelas, 2014). Zeolites resin is commonly used to remove heavy metals like Ni, Cu, Cd, Pb, Zn in sediment (Jamil *et al.,* 2010 & Alyuz & Veli, 2009). Secondary pollution produces due to Re-formation (recharge) of resin and require the reagent that also increases sediment treatment cost. Ion exchange is suitable for low pollutants. It is mostly used in laboratory purposes, at large scale, it increases the cost of sediment treatment (Bilal, *et al.,* 2013). In 1995 magnetic ion exchange use as ion exchange resin, it was used to remove natural matter (Ambashta & Sillanpaa, 2010).

Filtration Technique

Membrane filtration is one of the best filtrations because with the help of the process we can remove heavy metal as well as destruct other harmful microorganisms (Lyu, *et al.,* 2015). There is many factor that depend on membrane filtration, particle size, pH solution concentration and applied pressure (Barakat & Schmidt, 2010). The membrane is made up of porous material, this helps to separate metal from pollutant water (Patil, *et al.,* 2016). There are two types of ceramic and polymer. Ceramic material membranes are high in cost, and they are also weak (Mutamim, *et al.,* 2012). Membrane filtration also removes other Organic compound and suspended material.

Chemical Technique

The chemical precipitation (separation) method is one of the most common methods which is used in many industries because it is the comparably cheapest cost. By changing the pH metal precipitate form and not dissolve in a solution (Hashim *et al.,* 2011). Metal is extracted by sentimental process (FuWang 2011). Isolation of heavy metal like Cu^{2+}, Ni, Cd^{2+}, $Mn^{2+,}$ and Zn^{2+} (Tanong *et al.,* 2017). We can eliminate nickel and manganese by using sodium carbonate at pH 9. This method is suitable for higher concentration level of Ni, (Kuan *et al.,* 2010).

Electrochemical Treatment

Removal of heavy metal by electrochemical treatment, metals are moves towards their respective electrode this result in their separation (Trellu, *et al.,* 2016). Electrochemical treatment ability depends upon some factors like electrode material, mass transport, cell parameter, water composition and current density (Almeida, *et al.,* 2014). The demand of electrochemical treatment increases for the treatment of sediment day by day as we understand the importance of environmental pollution. When we compare electrochemical treatment to other treatments like Coagulation method, Chemical treatment method is much better because it does not produce any side product. The disadvantage of electrochemical treatment is that it requires large amount of energy and as well as requires high maintenance and it is also limited application due to the lifetime of electrode material because it is short (Zhang, *et al.,* 2013). This technique eliminates very low amount of heavy metal which is present in sediment due to this we can also say that its secondary treatment method. It works as secondary treatment process in front of ion exchange or precipitation treatment process (Le, *et al.,* 2009, Cui, *et al.,*2012).

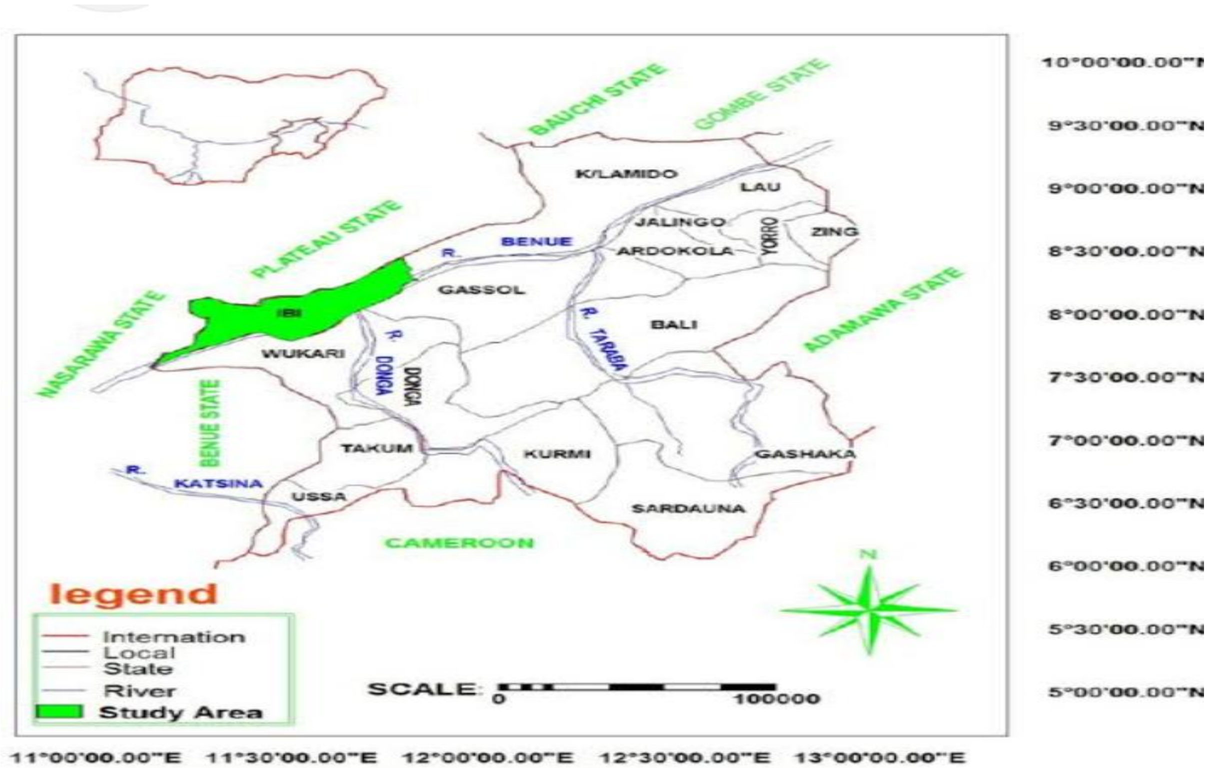
Adsorption

It is a very common process to the treatment of sediment. It is the cheapest method because the adsorbent of this process recharged (desorption) by several methods, which is environment-friendly like Thermal regeneration, electrochemical regeneration, pressure swing. This technique does not produce any toxic pollutants (Demirbas, 2008). By selecting adsorbents, consider some qualities such as less in cost, surface area pore size etc. Some factors also affect the efficiency of adsorbent like polarity, pore size distribution, surface area (Vunain *et al.,* 2016, Ewecharoen *et al.,* 2009)

MATERIAL AND METHODs

Study Area; The study was carried along River Benue in Ibi town, Ibi Local Government, Taraba State, Northeast Nigeria. The area lies between Latitude 8 10'52.39" N and Longitude 9 44'39.52"E of agricultural products. Due to the richness of the minerals in the parent rock; these soils are well suited for cultivation of maize, rice, guinea corn as well as arable farming and tree crops production.

The river Benue at Ibi is one of the main rivers alongside Donga, and river Taraba state. They rise from Cameron Mountains, straining from almost the entire length of the state in the north and south occupation of people in Ibi Local Government Area is fish farming.



(Gabriel *et al*., 2017)

Sample collection, treatment and preservation

Sediment samples were collected from the Ibi portion of the River Benue. The samples were collected in pre-cleaned zip bags. The choice of plastic containers for sample collection is for the fact that the level of contamination from it to the sediment especially from heavy metals is low (Odoh *et al.,* 2013). The sediment samples were collected at noon in the month of November, collecting sample at noon contributed to the high temperature readings. Triplicate of triplicate of sediment samples was collected, sample were collected from three points at the first River bank, the second Riverbank and the middles river segment. The collected samples were labeled with date and code. They were then taken to an open space with shelter and air dried. After air drying the sample was sent to the laboratory for further analysis.

Sediment sampling and chemical analysis:

This research presents Cd, Mn, Ni, Pb, and Zn concentrations in three sediments. Chemical analyses of river sediments are carried out within the framework of the State Environmental Monitoring. Chemical analysis was performed for a 5cm thick surface layer of the sediment collected over a 50m river stretch. Before chemical analysis, the samples were mixed; in this way, a so-called average sample was obtained for each river.

Sample analysis of Benue River at Ibi was done for the heavy metals' cadmium, nickel, magnesium, lead and zinc. In addition, other chemical parameters such as electrical conductivity, total hydrogen, pH, sulphate, nitrate, and phosphate were also determined using standard procedures. Besides this temperature measurements of samples were done on sample collection site.

The materials and equipment for sediment sampling analysis include:

Four plastic zip bags, Masking tape, indelible marker, and thermometer. The equipment and laboratory consumables used were an atomic absorption spectrophotometer (AAS) (Buck scientific Las Vegas USA), conductivity meter (DS-11), a pH meter (OHAUS ST210), oven, weighing balance, thermometer, distilled water, Kjeldahl flask and 2mm sieve.

Sediment samples were collected from River Benue in Ibi LGA, Taraba State. The samples were collected in pre-cleaned zip-lock bags, (Odoh *et al.,* 2013). Triplicate of sediment samples was collected from three points from Riverbank 1, Riverbank 2, the middles river region and a river in Wukari LGA, Taraba State as the control.

The collected samples were labeled with date and code. The samples were air dried and sent to the laboratory for further analysis.

Reagents for the analysis: Nitric acid (HNO_3), aqua regia, acetylene, acetylene/air, nitra ver 5, pho ver4 phophste and sulf3

Sediment Contamination and Potential Toxic Effect Assessment: The commonly used enrichment factors (EF), pollution load index (PLI) and geo-accumulation (igeo) were used to assess the contamination of river sediments. Moreover, to calculate the EF values, HMs were normalized, concentration in the sediment sample as well as concerning the geochemical background values (GBV).

Physicochemical analysis of sediment samples: From the samples collected, the following parameters were analyzed: pH, EC, THC, Nitrate, Sulphate, Phosphate and Temperature.

Determination of pH using Ohaus ST210 pH meter: The pH of each sample was measured with portable field pH meter.

Determination of Electrical Conductivity (EC): Conductivity of all samples was determined using a digital conductivity meter model 4520 JENWAY, serialNo 01263. The meter was switched on and allowed to warm up for about 15 minutes. It was then standardized with 0.01M KCI solution where a conductivity value of 1413 microsiemen per centimetre was obtained, the electrode was thoroughly rinsed with distilled water and then introduced directly into the samples. The value for each sample was taken (Bennet and David, 1974, Reda, 2016).

Sulphate: Sulfate content in the samples was measured by adding dissolved Sulfa Ver®4 pill in 25 ml of sample, followed by vigorous shaking to obtain a uniform mixture which was allowed settle for 5 min for reaction to take place. A spectrophotometer was set and run at a wavelength of 450 nm and blanks were used for calibration and

quality check.

Nitrate. For phosphate determination, Phos Ver ®3 Phosphate Reagent was used. All reagents were bought from HACH® Company in Dar es Salaam and parameters were measured in mg/L.

Phosphate: A spectrophotometer was set and run at a wavelength of 450 nm and blanks were used for calibration and quality check. Using Nitra Ver®5 P-Reagent for phosphate measurement at a wavelength of 890 nm. For phosphate determination, Phos Ver ®3 Phosphate Reagent was used. All reagents were bought from HACH® Company in Dar es Salaam and parameters were measured in mg/L.

Total Hydrocarbon Carbon: total petroleum hydrocarbon in the sediment samples was determined using gas chromatography-flame ionization detector while trace metal concentrations were determined with atomic absorption spectrophotometer (AAS), (Olusola *et al.*, 2019)

Temperature: The temperature of all the water samples was determined using a simple mercury-in-glass thermometer calibrated in degrees centigrade as described by Edema et al., 2001 and Dinrifo et al., 2010.

Heavy metal analysis

The soil samples were oven dried at 105°C for 24 h, followed by grinding and sieving using 0.18 mm sieve. 1.0g of dry soil sample was poured into a Kjeldahl flask and mixed with 25 ml of aqua regia 1:3 (1 conc. HNO_3: 3 conc. HCl). The mixture was digested on a hot plate at 95°C for 1 h and allowed to cool to room temperature. The sample was then diluted to 100 ml using distilled water and left to settle overnight. The supernatant was filtered prior to analysis using AAS.

Heavy metals were analyzed in the filtrate with AAS Buck 230, Buck scientific Las Vegas USA using air acetylene flame integrated mode, specific hollow cathode lamp and wavelength of each heavy metal and the concentration of each metal was obtained from the calibration curve of each standard. The following heavy metals: Iron (Fe), Lead (Pb), Copper (Cu), Sodium (Na), Potassium (K), Zinc (Zn), calcium (Ca) and Manganese (Mn), were determined for each water sample using AAS (Buck Scientific, VPG 230) procedure as. Each sample was digested using 100cm3 and a hallow cathode lamp of the desired metal was installed into the instrument and the wavelength characteristics of that metal was then set. The procedure used flame Atomic absorption spectrophotometry using acetylene/air. Concentrations of the analytes in mg/ml in the digested samples were obtained by extrapolation from the calibration curves prepared.

RESULTS AND DISCUSSION

The composition of the physiochemical parameters in sediment is shown in the table below. The results indicate that one of the concentrations of physiochemical parameters was above the standard set by world health organization (WHO) and National Environmental standards and Regulations Enforcement Agency (NESREA) and five were below the permissible limit on the samples analyzed.

- **Temperature**: The temperature of all the sediment samples was determined using a simple mercury-in-glass thermometer calibrated in degrees centigrade Dinrifo *et al*., 2010.
- The **pH** of each sample was measured using a portable field pH meter.
- **Determination of Electrical Conductivity (EC):** EC of all samples was determined using a digital conductivity meter model 4520 JENWAY. (Reda, 2016).
- **Sulphate**: Sulfate content in the samples was measured by adding dissolved Sulfa Ver®4 pill in 25 ml of sample, followed by vigorous shaking to obtain a uniform mixture which was allowed settle for 5 min for reaction to take place. A spectrophotometer was set and run at a wavelength of 450 nm and blanks were used for calibration and quality check.

- **Nitrate**: Using Nitra Ver®5 nitrate reagent for nitrate measurement at a wavelength of 890nm.
- **Phosphate**: For phosphate determination, Phos Ver ®3 phosphate reagent was used.

Total Hydrocarbon Carbon: Total petroleum hydrocarbon in the sediment samples was determined using gas chromatography-flame ionization detector while trace metal concentrations were determined with atomic absorption spectrophotometer (AAS), (Olusola *et al.*, 2019)

Table 1. Physico-chemicals Properties of the sediment **(mg/kg)**

Parameter	G1	G2	G3	A	G4	Standard WHO
Electrical conductivity (µS/cm)	114.550±0.000^{b}	105.625±0.007^{a}	226.775±0.007^{d}	148.983	176.910±0.014^{c}	1500.000
Total hydrogen content	0.000±0.000	0.000±0.000	0.000±0.000	0.000	0.000±0.000	0.000
Ph	8.000±0.000^{a}	8.200±0.000^{b}	8.400±0.000^{c}	8.200	8.600±0.000^{d}	6.5-8.5
Sulphate	1.560±0.007^{a}	0.815±0.007^{b}	1.255±0.007^{c}	1.210	1.345±0.007^{d}	240.000
Nitrate	14.910±0.014^{a}	9.335±0.007^{b}	11.460±0.014^{c}	11.902	13.950±0.007^{d}	40.000
Phosphate	1.640±0.007^{d}	1.450±0.000^{c}	1.435±0.007^{b}	1.508	0.985±0.007^{a}	5.000
Temperature ^{O}c	34.47±0.780^{a}	34.9±1.900^{b}	34.67±1.270^{c}	34.680	34.73±0.47^{d}	Ambient

Result presented as mean ± standard deviation. Results with the same superscript across the rows indicate no level of significance between them while result with different superscripts across the rows indicate level of significance between them (P<0.05).

Key: G1: Riverbank 1, G2: Riverbank 2, G3: Middle of the river sediment, G4: Control i.e A: Average of the composite meaning of sediment sample

The composition of heavy metal in sediment samples is shown in the table below. The results indicate that all the concentration of heavy metal was above the standard set by world health organization (WHO) and National Environmental Standards and Regulations Enforcement Agency (NESREA). Manganese and zinc has the highest level of contamination.

The soil samples were oven dried at 105°C for 24 h, followed by grinding and sieving using 0.18 mm sieve. 1.0g of dry soil sample was poured into a Kjeldahl flask and mixed with 25 ml of aqua regia 1:3 (1 conc. HNO_3: 3 conc. HCl).

The mixture was digested on a hot plate at 95°C for 1h and allowed to cool to room temperature. The sample was then diluted to 100 ml using distilled water and left to settle overnight. The supernatant was filtered prior to analysis using AAS.

Heavy metals were analyzed in the filtrate with AAS Buck 230, Buck scientific Las Vegas USA using air acetylene flame integrated mode, specific hollow cathode lamp and wavelength of each heavy metal and the concentration of each metal was obtained from the calibration curve of each standard.

Table 2; Heavy metals concentration (mg/kg)

Heavy metals	G1	G2	G3	A	G4	Standard (WHO)
Manganese	21.665±0.014 [a]	16.9550±0.049 [c]	28.1300±0.014 [d]	22.250	12.0550±0.007 [b]	2000.000
Nickel	1.255±0.014 [d]	1.1500±0.000 [b]	1.0500±0.000 [a]	1.150	1.2250±0.007 [c]	20.000
Cadmium	0.235±0.014 [d]	0.2600±0.000 [a]	0.1300±0.014 [b]	0.200	0.1700±0.014 [c]	3.000
Lead	0.330±0.007 [d]	0.3500±0.000 [c]	0.2850±0.000 [b]	0.321	0.1650±0.021 [a]	10.000
Zinc	27.265±0.007 [a]	29.3100±0.000 [c]	18.6600±0.014 [b]	25.070	33.2250±0.007 [d]	123.000

Result presented as mean ± standard deviation. Across the rows, results with the same indicate there is no significance while different superscripts indicate level of significance (P<0.05)

Key. G1; Riverbank 1, G2; Riverbank 2, G3; Middle of the river, G4; Control, A; Average composite meaning of sediments

Result presented as mean ± standard deviation. Across the rows, results with the same indicate there is no significance while different superscripts indicate level of significance (P<0.05)

Pollution load index (PLI):

PLI is the amount of stress placed upon an ecosystem by pollution and chemical released into the ecosystem by anthropogenic activities. Using the formula PLI = CF1*CF2*CF3*CF4*CF5/n.

The commonly used pollution indices include enrichment factor (EF), pollution load index (PLI) and geo-accumulation (igeo) were used to assess the contamination of river sediments. Moreover, to calculate the EF values, HMs were normalized, concentration in the sediment sample as well as concerning the geochemical background values (GBV).

- PLI = CF1*CF2*CF3*CF4*CF5/n

Where: CF is the contamination factor, which is calculated by dividing heavy metal by background value.

- EF=(M/N) Sample / (M/N) baseline

Where: M is the concentration of metals and N is the normalizer

- lgeo = log2(Cn/1.5Bn)

Where: Cn is the concentration of metal and Bn is the background value.

Table 3. Pollution load index

Heavy metals (HMs)	A	Background value (Bn)	CF
Manganese	22.250	2000.000	0.011
Nickel	1.150	20.000	0.058
Cadmium	0.200	3.000	0.067
Lead	0.321	10.000	0.032
Zinc	25.070	123.000	0.203

Pollution load index < 100 indicate the site is not polluted while Pollution load index >100 indicate high pollution or polluted site

PLI = 0.0000000555 indicating low pollution of sample site.

Enrichment factor (EF): EF is used to determine the increase in presence of elements due to human activities. Using the EF = (M/N) Sample / (M/N) baseline

Table 4. Enrichment Factor:

Heavy metals	A	Permissible limit(Bn)	EF value	EF class	Interpretation
Manganese	2.250	2000.000	EF<1	0.001	Uncontaminated to Moderately contaminated
Nickel	1.150	20.000	EF<1	0.057	Uncontaminated to Moderately contaminated
Cadmium	0.200	3.000	EF<1	0.067	Uncontaminated to Moderately contaminated
Lead	0.321	10.000	EF<1	0.031	Uncontaminated to Moderately contaminated
Zinc	25.070	123.000	EF<1	0.204	Uncontaminated to Moderately contaminated

Zn>Cd>Ni>Pb>Mn shows decreasingly uncontaminated to moderate contamination samples.

Table 5. Geo-accumulation of heavy metals Using the formula Igeo = log2(Cn/1.5Bn)

Heavy metals	A	Permissible limit(Bn)	Igeo value	Igeo class	Geo-accumulation index
Manganese	22.250	200.000	Igeo>1	-0.829	Uncontaminated
Nickel	1.150	20.000	Igeo<1	-1.180	Uncontaminated
Cadmium	0.200	3.000	Igeo<1	-0.055	Uncontaminated
Lead	0.321	10.000	Igeo<1	-1.377	Uncontaminated
Zinc	25.070	123.000	Igeo<1	-0.567	Uncontaminated

Cd>Zn>Mn>Ni>Pb which shows decreasingly uncontaminated sample because igeo<0.

Certainly! Here's your study discussion rewritten into clear, well-structured paragraphs for each point, with references integrated:

pH Concentration in Sediment Samples

The pH values recorded in the sediment samples ranged from 8.0000 to 8.6000, indicating slightly alkaline conditions. pH is a measure of hydrogen ion (H^+) and hydroxide ion (OH^-) concentrations, which determines whether a medium is acidic, neutral, or alkaline. In uncontaminated sediment, these ions are in equilibrium, resulting in a neutral pH of 7. The World Health Organization (WHO) recommends a pH range of 6.5–8.5 for water quality (WHO, 2020). The values obtained in this study slightly exceed the upper limit, suggesting the presence of alkaline substances possibly due to soil type and mineral dissolution. Although these values are not extreme, pH levels outside the recommended range can mobilize toxic metals, corrode infrastructure, and pose health risks such as skin and eye irritation at values above 11 or below 4, and irreversible tissue damage below 2.5 (Chapman & Kimstach, 2017).

Electrical Conductivity (EC)

Electrical conductivity (EC) measures the ability of sediment to conduct electric current, which depends on the presence of dissolved ions like calcium, magnesium, and chloride. The EC values in this study ranged from 105.6250 to 226.7750 µS/cm, exceeding the WHO and USEPA recommended limit of 100 µS/cm. These elevated values may result from agricultural runoff, industrial activities, or natural mineral content. Although EC does not directly affect human health, it serves as an indicator of water quality and potential contamination. Variations in EC could also be influenced by other sediment properties such as turbidity, which were not assessed in this study and warrant further investigation.

Sulphate Concentration

Sulphate concentrations in the sediment samples ranged from 0.8150 to 13.9500 mg/kg, which are significantly below the WHO limit of 500 mg/L. Sulphate is an inorganic salt derived from sulfuric acid and is highly soluble in water. In deep ocean environments with low organic matter, sulphate penetrates deeply into sediments. Conversely, in areas with high organic input, sulphate is rapidly depleted. The low sulphate levels observed in this study suggest minimal contamination and a relatively stable sediment environment.

Total Hydrocarbon Content (THC)

The total hydrocarbon content (THC) in all sediment samples was recorded as 0.0000 mg/kg, indicating no detectable hydrocarbon pollution. THC is used to quantify hydrocarbon impurities, which typically originate from petroleum-based contaminants. The WHO sets a permissible limit of 6.0 mg/kg for THC in sediment. The absence of hydrocarbons in this study suggests a clean environment with respect to oil pollution and related industrial activities.

Phosphate and Nitrate Concentrations

Phosphate levels in the sediment samples ranged from 1.4350 to 1.6400 mg/kg. These values are relatively low compared to typical soil phosphate concentrations, which range from 150 to 700 μg P/g. Low phosphate levels may be attributed to the age and nutrient status of the landmass, particularly in older geological formations (Neal, 2009). Nitrate concentrations ranged from 9.3350 to 14.9100 mg/kg, remaining below the WHO limit of 40 mg/L. While natural nitrate levels underground are typically low, human activities such as fertilizer application and waste discharge can elevate nitrate concentrations in sediment.

Temperature of Sediment Samples

The temperatures recorded in the sediment samples ranged from 33.67°C to 34.83°C. Elevated sediment temperatures can reduce light penetration in water bodies, thereby affecting photosynthesis and aquatic life. Sediment absorbs solar radiation, which increases water temperature and can disrupt ecological balance. These temperature values suggest a warm aquatic environment, possibly influenced by climatic conditions and sediment composition.

Heavy Metal Concentrations

Heavy metals analyzed in the sediment samples included manganese (Mn), lead (Pb), nickel (Ni), cadmium (Cd), and zinc (Zn). All concentrations were below WHO permissible limits, indicating no acute contamination. Mn and Zn exhibited the highest concentrations, followed by Ni, Pb, and Cd. Lead has no known biological function and is a potent neurotoxin, especially harmful to children and fetuses, even at low doses. It can impair cognitive development and cause blood and brain disorders (Raviraja et al., 2008). Cadmium, the least concentrated metal in this study, is a persistent bioaccumulate toxin linked to lung cancer, liver cirrhosis, and kidney damage (Atolaiye et al., 2006; Weiss & Wright, 2001; Hutton, 1987).

Ecological and Seasonal Influences

Although metal concentrations were low, their ecological impact should not be underestimated. The presence of one metal can influence the toxicity of another through synergistic, additive, or antagonistic interactions. Seasonal factors such as rainfall, geological formation, and solar radiation can affect metal distribution in sediments. For instance, runoff during the rainy season and reduced water volume during dry periods can alter metal concentrations and their ecological effects (Aremu et al., 2008).

CONCLUSION

This study has provided valuable insights into the concentrations of heavy metals and physicochemical parameters in sediment samples collected from River Benue in Ibi Local Government Area, Taraba State. The analytical results indicate that all measured heavy metal levels fall within the permissible limits set by the World Health Organization (WHO), suggesting that the sediment is not contaminated and poses no immediate environmental or health risks.

Recommendation

To preserve the quality of aquatic life, agricultural productivity, and water safety in the region, it is essential that sanitary inspection officers conduct regular monitoring of environmental activities within the locality. Particular attention should be given to manganese (Mn) and zinc (Zn) concentrations due to their elevated levels. Additionally, a geological survey is recommended to investigate the presence of mineral deposits—especially zinc—since its high concentration in the absence of industrial activity may indicate naturally rich mineral content in the soil.

Conflict of Interest

The author affirm that there are no conflicts of interest associated with this publication.

Authors' Declaration

The authors confirm that the research presented in this article is entirely original. They accept full responsibility for any claims or issues arising from the content herein.

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