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RESEARCH ARTICLE

AN EXPANDED SYNOPSIS ON THE DYNAMICS OF SEDIMENTS, HEAVY METALS, AND NUTRIENTS IN THE KWA IBOE RIVER BASIN, NIGERIA

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ABSTRACT

The quest for sustainability of river ecosystem and allied resources in this 21st Century constitutes a major source of concern for the United Nations programme on sustainable Development Agenda, but with limited success due to human exploitative excesses and climate change impacts. This study employed the direct field survey and laboratory techniques. The bedload sediment and surface water samples were collected from eight sampled points along the river during the months of November, February, April, and July, making a total of 128 surface water and sediment samples. Also, the laboratory analyses were carried out on 24 heavy metals and 24 nutrients for sediment and water making a total of 48 parameters at each point and 384 parameters for each month. A grand total of 1,536 heavy metals/nutrients were analyzed during the study period. The granulometric assessment showed a dominance of mean diameter of 0.50 and 1.00 mm. Using Principal Component Analysis, the metal parameters were collapsed into five major (core-metal, crustal-metal, Vanadium-ore, ferromanganese**,** and manganese) components each with an eigenvalue greater than 1.00 that explained 95.09 of the total variance in the series. A comparison of metals and nutrients concentration in the surface water with the World Health Organization (2004) standard showed that the KIRB is seriously polluted with lead, cadmium, chromium, selenium, and nitrite. This study recommended for urgent moved by stakeholders to synergize in protecting the fragile and moderately threaten Kwa Ibo River eco-geomorphologic unit of Southeastern.

Keywords: Kwa Iboe River, water, sediment, heavy metal, nutrients, eco-geomorphic units

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1.0. INTRODUCTION

River basins, their estuaries and Oceanic shelves are fundamental fluvial eco-geomorphologic units that provide viable environment for the growth of flora, fauna, and human beings. The fluvial landforms such as floodplains, valleys, and deltas (Umo, 2019), often provide rich landscapes for agriculture, deposit of minerals, fishery and other sea food stocks. They also provide sheltered areas which are favorable to host port facilities, water, and sediment to link the coast to inland navigation, industries, and settlement (Achete, 2016). Hence the history and levels of human civilization are linked with their fluvio-geomorphologic environments (Pennington, Bunbury and Hovius, 2016). Natural and anthropogenic variables at a basin scale often contribute to the pollution of river water and bedload sediment (Sparks, 2005) and alter the spatial distribution of sediment size.

The discharge (water and sediment) properties of rivers to the ocean constitute a crucial component of the global water balance. Such properties usually trigger the geomorphic hazards, channel modification, quality contamination, siltation, modification of stratigraphic sequence, and influence pattern in watershed management practices. Umo (2019) had emphasized the need to establish a sustainable ecological relationship between human and nature at a basin scale to appreciate its heritage, importance, and protect its quality. Such attempts especially in the humid Tropical Rivers especially Kwa Iboe and Ikpa are rather eclipse (Umo and Enwereuzor, 2021; Umo, Enwereuzor, and Ezemonye, 2021), or grossly ignore (Andem et al, 2013; Udosen & Benson, 2013). Such neglect can be attributed to variations in researchers’ interests, ignorance, apathy, and/or limited capacity. The highlighted neglects/ flaws have not only increase people and rural livelihood vulnerability to the dangers of metal pollution, but also exacerbate biodiversity loss and extinction of some exotic species that are endemic in the basin area.

Physical geographers, earth scientists, and geomorphologists in particular have devoted most of their research efforts, time, and other resources to facilitate the understanding of the dynamics of fluvial processes and landforms in the 21st century (Meitzen, Doyle, Thoms, and Burns, 2013). In the context of River basins, topography, vegetation, climate, geology, and man are among the major factors that facilitate weathering, erosion, transportation, and deposition (National Research Council (NRC, 2012)). Understanding of spatio-temporal dynamic among the surficial phenomena is at the core of geomorphologic research (Brierley, Fryirs, and Jain, 2006), notably sediment size distributions, heavy metals, nutrients, and the influence basin area geomorphometry on the particulate matters circulation at a river basin scale.

Sediments are rock materials formed due to weathering and denudation of materials found at/near the bottom of rivers, oceans, and other fluvial/rock systems (Jones, 1969; Depetris, Pasquini, and Lecomte, 2014). The quantity of sediment generated during discharge is called sediment yield (Lin, Lin and Chou, 2002; Heng and Suetsugi, 2013). The sediments may vary

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based on their granulometric distributions across eco-geomorphologic units over time and have formed the focus of research from different fields in geographical and earth sciences. Oldroyd and Grapes (2008) opine that it is often at the center of geomorphological inquiries because of the concern for Earth's surface features and processes with information that is more amenable to field observations and laboratory analyses. The need to used integrated approaches in exploring such opportunities at the river basin scales have been emphasized recently in Knox (2006); Bendix and Vale (2014); Umo (2019).

The capability of a river to distribute sediment particles from the upstream (eco-geomorphological units) to the estuary is controlled by river discharge, which in turn is a function of climate, vegetation, topography, rock properties, soil, geology, and size of the river basin (Sigleo and Frick, 2007). The hydrologic cycle controls the timing and volume of their delivery from various eco-geomorphologic units of a River basin to the Ocean. The concept "eco-geomorphology" is an interdisciplinary approach to the study of a river system that integrates geomorphology, hydrology, and ecology (Thoms and Parsons, 2002; Mondal, 2014). It also represents the functional interactive unit among biotic (e.g. plants, animals, man) and abiotic (notably climate, sediment/soil, and landform) components.

Variations in global weather and climate suggest the tendency for a continuous sea level rise of 18 - 59cm during the 21st century (Sander, Deicke, and Karius, 2011), with the corresponding devastating effects of diverse geomorphic hazards (flooding, erosion etc.) and processes (weathering, discharge etc.) that alter the landforms, generate, transport, or deposit loads (sediment, heavy metal, and nutrient) which together affect the quality of river system and grain size distribution. Besides, the scenario of weather/climate variability impacts often vary in space and time (Turki, Medina, Gonzalez and Coco, 2013), and are most likely to be worse in the Humid Tropics due to extreme weather/geomorphic activities and anthropogenic interferences (Shajan, 2001), thereby necessitating for more information through researches in context of the River Basin.

The population concentration in coastal areas and river basins have been projected to increase (Woodroffe, 2003), from 3.6 billion in 1995 to 6.4 billion (signifying 75% of the world's population) by 2025 (NRC, 2010), along with urbanization, industrialization, and socio-economic activities. Within the Kwa Iboe River Basin, accelerated socio-economic activities tend to take a different dimension due to petroleum and natural gas exploitations and spills (from the on-shore and off-shore activities of oil/gas producing and allied servicing companies), discharge of untreated domestic and industrial effluents, used of chemicals for agricultural and other activities in the basin area (Udosen and Benson, 2006; Ephraim and Ajayi, 2014), constitute major sources of heavy metals and nutrients in surface water, and bedload sediment (archives of pollutants) (Sparks, 2005) but with limited monitoring through research (Ituen and Johnson, 2015) and valid management options.

1.1. Aim and Objectives

Drawing from the preceding background, this study evaluates a synoptic exploration of sediments, heavy metals, and nutrients in the Kwa Iboe river basin (KIRB). To actualize the aim, the following specific objectives guided this study:

1. To examine the spatio-temporal dynamics in the distribution of bedload sediment characteristics in KIRB.
2. To evaluate the effect of variation in basin area geomorphometry on sediment and particulate matter distributions in KIRB.
3. To determine the interrelationships among the heavy metal (lead, arsenic, cadmium, chromium, copper, iron, mercury, nickel, selenium, manganese, vanadium, and zinc) parameters in bedload sediment and surface water of KIRB.
4. To analyze the inter-correlations among the nutrients (nitrogen, nitrite, nitrate, ammonium, sulphate, calcium, organic carbon, potassium, chloride, magnesium, pH, and sodium) concentration in bedload sediment and surface water of the KIRB.
5. To carry out a comparative assessment of the spatio-temporal dynamics in heavy metals and nutrients concentration in surface water of the KIRB with the WHO (2004) standard

2.0. THE STUDY AREA

2.1. Location and Local Geomorphology

The Kwa Iboe River Basin (KIRB) is located between Latitude 4^0 20' and $5^0$40' North of the Equator and Longitude 7^0 10' and $8^0$25' East of the Greenwich Meridian (Figure 1). The River takes its source from Okwuta community in Umuohia North, Abia State where it flow in a south direction as a first-order stream, joined by other tributaries to drained Anya River near Umudike. It flows across several Local Government Areas in Abia and Akwa Ibom States and empties into the Atlantic Ocean at two communities:- Itak Abasi on the East and Inua Eyet Abasi on the West (Andem *et al.*, 2013) in the Ibeno Local Government Area (Umo, 2019,;Umo et al., 2021).

The KIRB drains the coastal plains sands and the alluvial deposits of Southeastern Nigeria. It is primarily depositional in nature, with ridges, valleys, and plains, rich in earth minerals (Usoro, 2010, 2010a). The basin has an appreciably high, yet dynamic relief with the highest elevation of 550 meters above average-sea-level (ASL) at the divide separating Imo, Itu, and Kwa Iboe Rivers around its source in Okwuta, Umuohia North, the Abia State Capital (Topographic Maps of the Federal Survey Department, 1966). At the middle portion of the basin (e.g. Essien Udim, Nsit Ibom) the elevation range between 80 and 350 meters. At the areas close to the estuarine environment (Eket and Ibeno), the relief pattern consists of low-lying plains with the heights that range between 20 - 40 meters (ASL). At the estuarine (Ibeno) environment of the Kwa Iboe River, the relief is very low (0 – 10 m) above mean sea level due to the influence of the Atlantic Ocean on the estuary where Ibeno beach is located (Umo, 2019).

As one of the youngest and low depositional surface, Kwa Iboe River drains a proportion of the Nigerian coastal belt. Its geographic location also exercises significant influence on the landforms development in the basin area. However, the major topographic/ fluvial features in the area comprise ridges, ripples, sandy terrain, shallow depressions, denudational slopes, dry valleys, floodplains, ravines/gorges, gullies, fluvial terrace, levees, back swamps, cutoff channels, river channels, point bars that give the area its uniqueness.

There are two outstanding geologic formations that traverse the Kwa Ibo River Basin area. These geologic formations are the Coastal Plains Sands, and the Beach Complex and Alluvial Deposits (Umo, 2019). There are traces of geologic formation notably the sand-gravel facies (Ameki formation); and the shale-limestone facies (Imo shale) which are the older and occupy very insignificant portion along the divides of the Imo, Itu, and Kwa Iboe Rivers. Comparatively, the Coastal Plains Sands covers over 65 percent of the total wetland and allied landform in the area, while the Beach Complex and Alluvial Deposits and the sand-gravel facies (Ameki formation); and the Shale-Limestone Facies (Imo Shale) make up the residual geologic formations (Umo, 2019).

The Kwa Iboe River is the third largest and longest river basin that drains southeastern Nigeria. The River is a fifth-order basin, with six fourth-order sub-basins, eleven third order sub-basins with numerous second-order, and first-order sub-basins. These sub-basins are evenly distributed across the upper part, middle part, and the lower part of the basin. The distribution of the various sub-basins across the River basin whose area is approximately 4074.17 km^2 is attributed to the nature of its topography, geology, climate, soil, and local geomorphology. Generally, the river and its tributaries possess dendritic pattern which suggests normal process of evolution.

At the lower part (estuarine region), the River has many Creeks and lagoons accelerated by protracted deposits of the tertiary and quaternary times. Major ones include the Stubbs, Douglas, Elechi, Mbat-Abbiati, and Oberakkai Creeks where most of the anthropogenic activities such as oil exploration, commercial fishing, lumbering, domestic and industrial effluent discharges are carried out (Udosen and Benson, 2006). The downstream region of the River Basin (Creeks, lagoons, estuary and the adjacent continental shelf of the Atlantic Ocean) provide functional units for numerous aquatic organisms especially periwinkles, fishes, crayfish, turtles, crocodiles, alligators and other sea food to breed and feed their young ones.

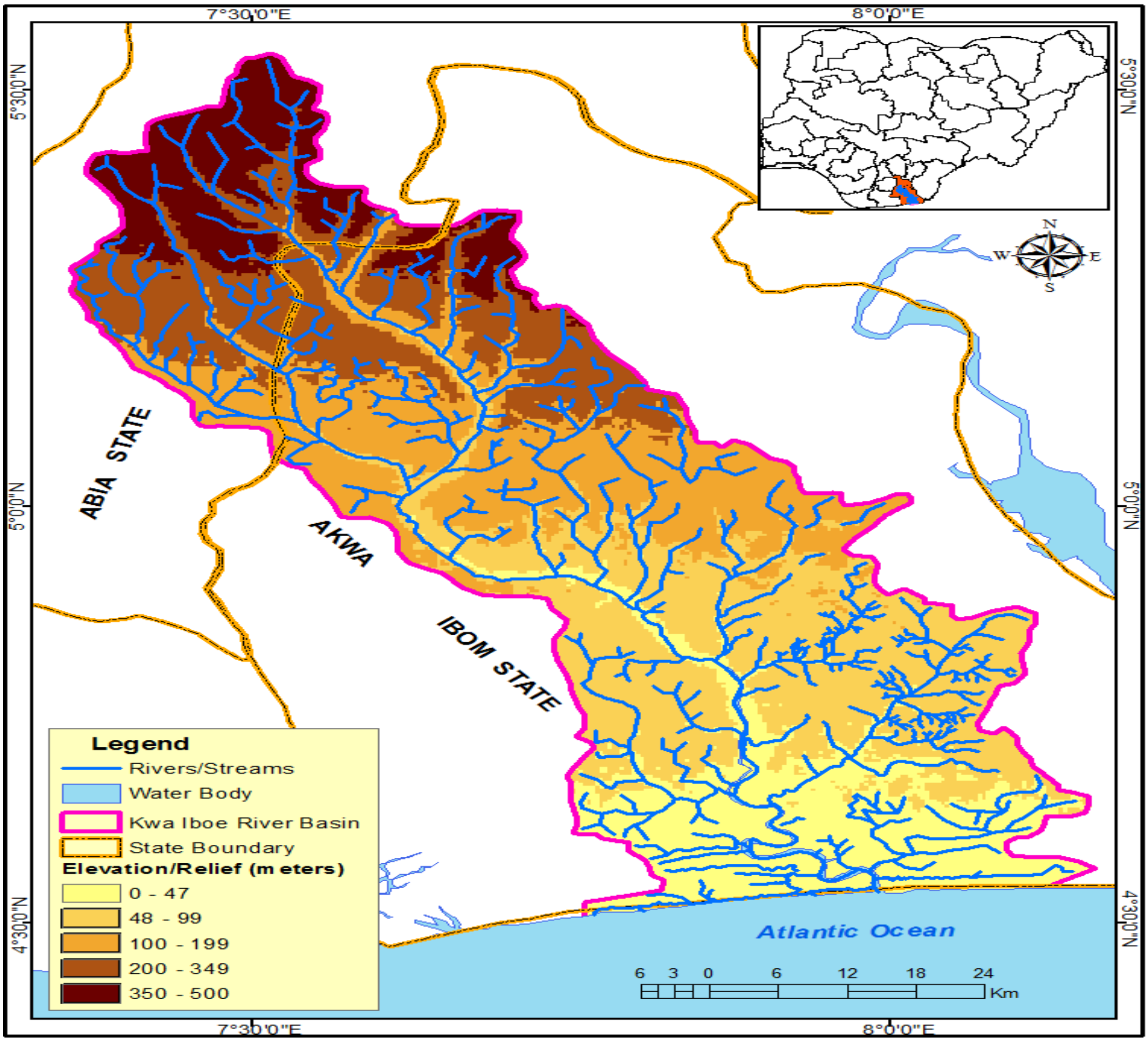

Figure 5: Kwa Iboe River showing the Relief and Drainage System.
Source: Extract from US Geological Survey Department using Shuttle Radar Topography Mission (SRTM, 2018) on a 30 Meter Resolution.

2.2. Climate

The climate of the KIRB area is classified as Tropical Humid (Af) climate based on Köppen's climatic classification system. The annual rainfall amount within the catchment region is usually very high with an annual average ranging from 2500mm to 3000mm (Udosen, 2008; 2012). The immensity of the basin suggests variability in rainfall; hence the amount, intensity, duration and severity of rainfall usually decrease with distance from the estuary due to the influence of the Atlantic Ocean and coastland circulations. For instances,

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areas around the estuarine (Ekpenekang, Mkpanak and Okoro Ete) usually received rain throughout the year while in the upstream areas (Umudike and Obot Akara, Ikot Osurua etc), rainfall often lasts for 8 - 10 months annually (Udosen, 2012; Ituen and Johnson, 2015). The peaks of rainfall usually occur during the months of July and September (Udosen, 2012), thus, reflecting double rainfall maxima in a hydrological year (Umo 2019).

The mean monthly temperature of the area is approximately 27^{o}C with a range of about 5^{o}C, but changes do occur based on the season. The average maximum temperature is 31^{o}C (February) and the coldest month (July) temperature often falls below 24^{0}C (Udosen, 2012; Ituen and Johnson (2015). Evaporation in the area is usually very high depending on temperature. The relative humidity within the basin area is often high, ranging from 75 to 100 percent. Similarly, the amount of insolation and sunshine hours are usually influenced by the nature of cloud cover and seasonal changes (Udosen, 2012). Each weather and climatic variables (rainfall, temperature, insolation etc.) often vary with season.

2.3. Vegetation

There are two dominant types of vegetation in the KIRB area. The upper and the middle stream areas are dominated by the tropical rainforest belt with secondary vegetation that is altered by diverse human occupation in the region and selected primary forests. These parts of the River are dominant source of water for domestic and agricultural uses. The estuarine belt is rich in mangrove vegetation. The area is usually swampy with two vegetation type (fresh water swamp and salt water swamp). The salt water is found in Creeks and usually possesses high salt content due to their proximity to the Atlantic Ocean (Figure 3). The trees in the area possess aerial root system. The nature of mangrove vegetation is influence by salt water and human activities.

The Kwa Iboe River is one of the largest fishing settlements on the Nigerian coastland. The estuarine areas of Ibeno, the low lying terrain are often submerged during the months of June to October (Andem *et al*, 2013. The coastal area of the basin is highly rich in hydrocarbon, clay and gravel deposits and has formed a viable unit for the exploitation and exploration of crude oil by both national and multinational companies and oil servicing firms within various locations in Eket and Ibeno including ExxonMobil, Trebelyn Oil and Gas. Other aspect human activities that are of environmental concern in the river basin include (gas flaring, dredging, sand mining, fishing, farming, laundering, and urbanization).

The prevalent human activities in the area have the potentials of increasing the toxic elements, nutrient enrichment, and sedimentation and the corresponding pollution/ contamination level of the River system with the attendant ecological and economic impacts on man, aquatic organisms, plants, and the environment.

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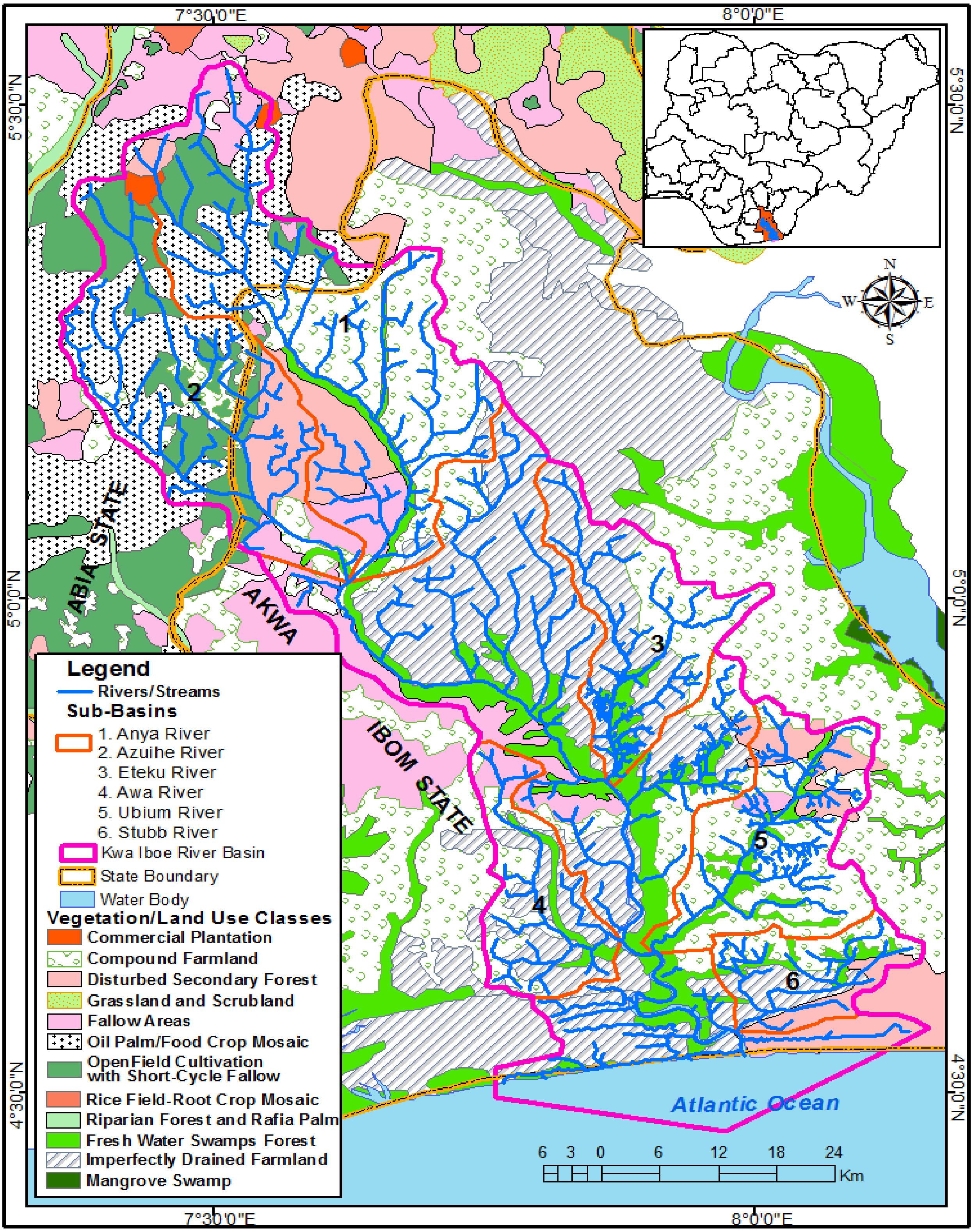

Figure 3: Kwa Iboe River Basin Showing the Distribution of Vegetation and Land Use.
Source: Modified from Cross River Basin Development Authority (1983).

The uniqueness of the sceneries according to Ituen and Johnson (2015) provide exceptional sites for tourist activities, fishermen and above all the ExxonMobil Terminal Gulf course facilities and other socio-economic activities for the development of the basin area. Other dominant land use types in the basin area are agriculture and animal husbandry: large-scale fish farming (aquaculture), intensive and extensive crop production (cassava, yam, maize, vegetables, and rice), animal production (goat, sheep, pig and birds), commercial fishing and hunting (Umo, 2019). Similarly, population increase in the basin area tend to accelerate the level of scramble for and colonization of land for housing, industrialization, administration, marketing, political, agricultural, and allied commercial activities especially at the Umuohia, Ikwano, Uyo, Eket, Ikot Abasi, Ibesikpo Asutan, and Ibeno Local Government Areas of KIRB, Southeastern Nigeria.

3.0. METHODOLOGY

This study employed a direct field survey and laboratory techniques. The Kwa Iboe River Basin was stratified into eight sub-units comprising one (1) first-order tributary (where the River originated from), six (6) fourth order (Anya, Azuihe, Awa, Eteku, Ubium, and Stubbs) Rivers, and the estuary (where the river enters the Atlantic Ocean). The grab water and core bedload sediment samples were collected along the transects without disruption and their coordinates recorded using Global Positioning System before packaged, labelled, and transported to the laboratory.

The samples were collected during the months of November (2017) for early dry season; February (2018) for peak dry season; April (2018) for early rainy season; and July (2018) for peak rainy season, making a total of one hundred and twenty-eight (128) surface water and bedload sediment samples (Umo, 2019, Umo & Enwereuzor, 2021, Umo, Ezemonye, & Enwereuzor, 2021). Each of the sediment and water samples was given appropriate treatments to ensure standards compliance during collection, packaging, transportation, storage, and digestion to sustain standards compliance. The laboratory analyses were carried out on 24 heavy metals and 24 nutrients parameters for bedload sediment and surface water each making a total of 48 parameters at each point, 384 parameters during each month, and a grand total of one thousand five hundred and thirty-six (1,536). The Atomic Absorption Spectrometer (AAS Optima 210-Perkin Elmer) was employed in the analyses of heavy metals. Different methods (notably colorimetry, titration, etc.) were used for the determination of nutrients concentration in bed sediment and surface water.

In order to determine the grain size distribution of bedload sediment, Wentworth (1922) grade scale was modified using a five-point (sieved) scheme for sand. The five class limits used in this study comprised gravel (>2 mm), very coarse sand (2 - 1 mm), coarse sand (1 – 0.5 mm), medi-fine sand (0.5 – 0.05 mm), and superfine (<0.05 mm). The sediment statistical description was based on Folk and Ward (1957) Logarithmic model. Data from bedload sediments, surface water, and basin area geomorphometry were analyzed using descriptive statistics (percentages, mean, standard deviation, kurtosis, skewness etc.) and multivariate statistics (principal component analysis, regression models, correlation analysis, analysis of variance, t-statistics, paired samples statistics, etc. The Statistical Package for Social Sciences (SPSS), version 22 was used for statistical analyses. Each test of significance was done at 0.05 confidence level.

4.0. DISCUSSIONS OF RESULTS

The results that were reached at the course of this study are synoptically presented thus.

The sediment granulometric assessment showed the dominance of mean value that range of 0.50 - 1.00 mm designated as coarse sand. The standard deviation showed the dominance values of 0.70 and 1.00 mm designated as moderately sorted. The very high proportion of moderately sorted bedload sediment suggests the rising potential of drying up of 1st order river tributaries as orchestrated by the highly porous and permeable nature of the sand particles emanating from the Coastal Plains Sands Deposits of Tertiary Times. The finding collaborated Umo (2019) notion that the Coastal Plains Sands covers over 65 percent of the total landform in the basin area. On the basis of mathematical modelling, the elaborate perspectives are presented Umo *et al*. (2021).

2. The influence of basin area on the particulate matters gave a positive coefficient of 0.954 that explained 90.4 percent of the proportion of variance. A further probe of the result using ANOVA test revealed that variations among the parameters were not statistical significance at 95 percent confidence level in the series. A juxtaposition of the result validate the reality of fairly uniform patterns in geology, soil, relief and the corresponding fairly homogenous nature of the magnitude and frequency of fluvial geomorphological processes that are operational across distinct geographical spaces (sub-catchments) of the Kwa Iboe River Basin in Southeastern Nigeria.

3. A regression model of the effect of gravel on the sand sizes yielded a coefficient of 0.978. The ANOVA model offered 16.4 and the Table value of 9.117. Thus, variations in gravel have statistical significant effect on the distribution of sand sizes across distinct eco-geomorphic locations and climatic seasons in the Kwa Iboe River Basin as reiterated and validated in Umo and Enwereuzor (2021).

4. The PCA was used to reduced 24 metal variables five major (Core-metal, crustal-metal, Vanadium-ore, ferromanganese, and manganese) components each with an eigenvalue greater than 1.00 that explained 95.09 percent of the total variance in the series. The inter-correlations among nutrients parameters using PCA retained fluvio-cation, halite, pedo-carbon-nitrate, pedo-ammonium-nitrite, and carbon-nitrogen, each accounting for over 75 percent of the strength of relationships in the series. The assessment of combined effect of variations using ANOVA model gave F value of 7.390 and a Table value of 3.220 which

sustain statistical significant dynamics in the spatio-temporal concentrations of heavy metals and nutrients in KIRB.

5. The concentration of metals and nutrients in the surface water depict dynamics in space and time. A comparison of the result of each parameter with the WHO standard yielded high pollution level of heavy metals such as lead, cadmium, chromium, nickel, zinc, arsenic, manganese and mercury. The notions collaborates the critical evaluations presented in Umo, Okoroafor & Ukwe (2024). The implication is that sustainability in the management and protection of Kwa Iboe River resources and its ecosystem must start from the point of origin of various sub-catchments to facilitate the entire river self-purification and people and ecosystem utilization and health. The expanded versions of the highlighted findings are elaborately explored in Umo (2019) and Umo (2025).

The dimensionalities of granulometry and fluidities metals and nutrients in bed sediments and surface water bed nutrients and the findings are indications that though anthropogenic activities such as land preparation practices, use of agro-chemicals, deforestation, sand and hydrocarbon mining, urban/industrial waste disposal, and other farming activities played accelerating role in certain heavy metal fluxes in fluvial properties (e.g. lead, arsenic, mercury, cadmium, and chromium); the geologic formations and local geomorphological processes tend to exercised primary influence on the pattern of concentrations of the identified heavy metals in fluvial properties across the sampled sub-catchments of the humid Tropical River.

5.0. CONCLUSION

This study established the granulometric status of the KIRB. The particle size distribution has successfully been classified as a coarse sand bed with a moderately sorted pattern, and a very fine skewed with a very Leptokurtic in nature. Moreover, it is clear that from the preceding discourses that variation in the spatial distribution of gravel in the KIRB has a very strong effect on the very coarse sand, coarse sand, medi-fine sand, and superfine sand distribution. The statistical test sustained the notion that variation in the basin area geomorphometry influence sediment/ particulate matter distributions in the KIRB; such influence was not significant in the context of this research.

This study also established variation in the basin area geomorphometry influence sediment/ particulate matter distributions in the KIRB; such influence was not significant in the context of this research. The intriguing relationships of metals and nutrients in the Kwa Iboe River system have been validated and new process-based geomorphic concept (core-metal, crustal-metal, fluvio-cation, pedo-carbon-nitrate etc.) developed. This study established both qualitatively and quantitatively, each element status and identifies major ways the Kwa Iboe River ecosystem can be sustainably protected/managed/utilized.

The governments, ExxonMobil Company, and non-governmental agencies should form synergy and provide enabling ground for the taskforce that will enforce existing Laws and Regulations against indiscriminate dumping of untreated and hazardous wastes from land users, water users, oil service industries, household, and institutions closer/into the gutters, River and/or Ocean. The old laws and regulations need be revisited with stiffer penalties to serve as deterrent to the defaulters.

Competing Interest

The author declares that no conflicting interest exist in this manuscript.

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