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Department of Geography and Meteorology
Nnamdi Azikiwe University, Awka

SEDIMENT CONTAMINATION AND THE IMPLICATIONS OF ITS MINING IN THE ANAMBRA DRAINAGE BASIN, SOUTHEAST NIGERIA

Ayogu, Chinero Nneka[1*]; Maduka, Raphael Iweanya[2]; Ayogu, Nnadozie Onyekachi[2]; Nwabueze, I. Igu[3]

[1] *Department of Geography, University of Nigeria, Nsukka, Nigeria.*

[2] *Department of Geology, University of Nigeria, Nsukka, Nigeria.*

[3] *Department of Geography and Meteorology, Nnamdi Azikiwe University, Awka.*

[*]*Corresponding Author:* Ayogu Chinero Nneka. Email: chinero.ayogu@unn.edu.ng, Tel: 08068544287

Abstract

River sediments are mined in the Anambra drainage basin despite its contaminant loading. During the rainy and dry seasons, sediment samples were obtained from the six sub basins at the upper and downstream segments and were subjected to geochemical and geotechnical analyses using X-ray fluorescence (XRF), X-ray diffraction (XRD) and scanning electron microscope (SEM) imaging. The soil samples collected were also analysed to determine its physical properties. It was noted that potential toxic elements (PTEs) - Zn, Ni, Mn, Fe, Cr, Pb, V, Mo, Sc and Eu, were within the World Health Organization recommended limits while contamination degree (CD), modified degree of contamination (mCd) and pollution load index (PLI) revealed that the sediment PTEs' concentrations ranged between slight contaminations to severely polluted. Better sediment quality exists at the upstream during the rainy season. From, SEM, sediments showed high content of quartz. Particle size distribution (PSD), porosity –cum- bulk density, aggregate stability (AS), mean weight diameter (MWD), dispersion ratio (DR) and Roslan and Mazidah (ROM) scale of the soil suggests intense erosion as within the basin. Erosion and anthropogenic activities are major source of sediments and PTEs into the river channels.

Keywords: Anambra drainage basin; PTEs; Sediment mining; Erosion; Anthropogenic activities.

1.0 Introduction

1.1 Background Study

The hydrosphere is a vital part of the environment. Its integrity is under compromise due to advancement in man's socio-economic activities and natural processes. Progressively, intensified basin utilization has created a pathway for violation of its quality index (Albering*et al.* 2016; Petrosyan*et al.* 2019; Tochunwou*et al.* 2012). Most worrisome is the pollution emanating from heavy metal accumulation with its large-scale adverse effect on basin ecology, man and engineering structures (Aprile 2014).

Anambra drainage basin is an epicentre of hydro carbon, and covers significant section of middle belt and south eastern Nigeria. Its areal coverage is 14,006.69km (Ayogu *et al*. 2019a). The basin is exposed to frequent submergence and is sediment laden (Nwajide *et al.* 1996). Ayogu (2019b) noted a high load of potential toxic metal which are of anthropogenic origin in the basin. Petrosyan *et al.* (2019) reported that, daily, rivers are polluted with all kinds of domestic and industrial waste, agricultural inputs, garbage and construction wastes which accounts for more than 99% of heavy metals existing in water bodies worldwide (Singh et al. 2017). Albering *et al.* (2016), Tochunwou *et al.* (2019) and Zhang *et al.* (2018) decried the rate at which surface waters are polluted.

Reddy and Reddy (2011) enunciated that most waters with heavy metal has a positive correlation with reduced strength, elongated moulding period and premature hydration (Tashiro1980) when utilized for casting of mortar for construction works. This is due to high contaminant loading (Ivanka 2016). Thus, high load of heavy metal in geo-materials sourced from rivers affects its usability and results in weak response to structural designs (Zhang *et al.* 2018; Vega *et al.* 2004; He *et al* 2005). In consonance, Aprile (2004) pointed out that heavy metal affects geotechnical properties-specific gravity, optimum water content, pH-cum-acidity index. Ivan and Ikuo (2011) has decried excessive acidity of engineering soils due to the fact that acidity degrades the usability of soil for construction by impacting on the soil strength and its response to stress and strain. Agreeably, Yan-Jun *et al.* (2004) established that Zinc has a negative effect on engineering soil. This is because; it inhibits hyhdration-cum- pozzolanic process which calumniates in poor bonding of soils.

Anambra drainage sediments are used for construction; thus, sediment mining is a constant practice within the basin despite being contaminated with potential toxic elements (PTEs). Sudarsan *et al.* (2015) avowed that heavy metals hinder engineering properties of sand and proposed their removal through eco-friendly practices viz-a-viz bioremediation -using *Bacillusmicrobes*.

Iron (Fe), Mn, Ti, Al, Ca, Mg and Cr were identified as heavy metals that poses a threat in the environment with respect to engineering works –viz –a viz road construction (Barisic *et al.* 2017; Gomes and Pinto 2006). As a sequel, Sudarsan *et al.* (2015) reported that heavy metal laden sediment are conveyors of carcinogenic substances and such geo-material is amenable to weathering (Minu*et al.* 2018) and biological substances is due to high permeability-cum-accumulation of PTMs (Saeedi *et al.* 2011).

In pursuance of the above, the authors have proposed that contaminated basin has far reaching consequences on all hydro-system and structures therein. Objectively, this paper will determine the fitness of sediment in Anambra drainage for construction works, taking into cognizance its implication on health and the environment.

2.0 Methodology

2.1 Study Area

The study area is located largely within two states of south-eastern Nigeria- Enugu and Anambra States and one state in the North-Central-Kogi State. The Anambra River originates at Ankpa in Kogi State. From there, the river meanders through other states southward to empty into the River Niger at Onitsha. The longitudinal and latitudinal locations of the drainage basin extend from 6º 00ʹ N to 7° 30ʹ N and 7° 00ʹ E to 7° 30ʹ E (Fig. 1).

Geographical location of the research is within the humid tropics wherein there are seven months of rainfall that measures 1750mm to 2000mm (Ireland 1962), while dry season experience lasts for five months with February to April as the hottest months. Significantly, the wet season is interrupted with little dry season in the month of August known as "August break". The temperature condition of the research area is such that the mean annual temperature range is 27° C to 28º C.

The relief of the basin supports highlands and plains which are underlain with rocks of Palaeocene age to Quaternary climate. The basin is situated within the southern Benue Trough which is underlain by geological succession of alluvial and coastal sands deposited in the Quaternary era and Tertiary rocks-cum-Cretaceous sedimentary sequences such as the Imo, Ajali and Mamu Formations as shown in Fig. 2.

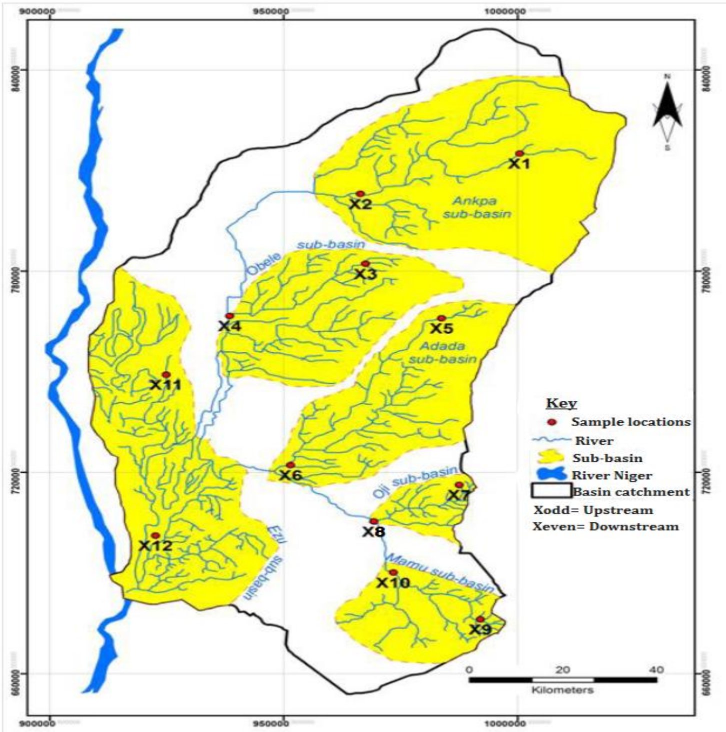

Fig. 1 Map showing sub-basins and sampling locations

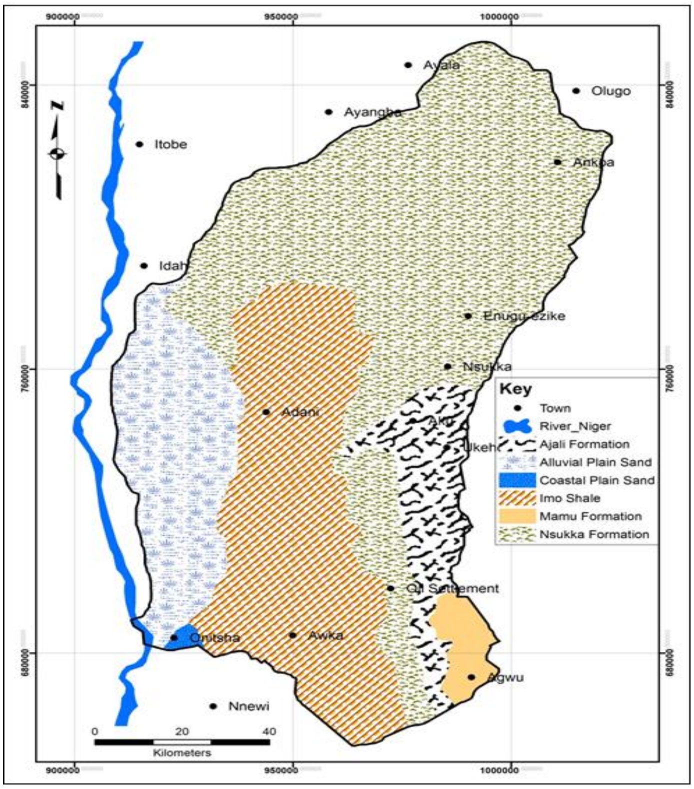

Fig. 2: The local geology of the Anambra basin

Apart from the falsely bedded Ajali sandstone that dominated the elevated (crest) sections of the basin, the majority of the vast area is covered by shaley low lands (Ayogu *et al.* 2019a). The Anambra drainage basin can be described as dendritic system. It flows southwest and drains into the River Niger.

Weakly consolidated ferralitic and hydromorphic soil dominate the basin. The area is dissected by maze of rivers which makes it vulnerable to surficial fluvio-geomorphic processes (Ayogu *et al.* 2019a). Within the drainage basin, deforestation without reforestation has defaced the green reserve of the area. Phil-Eze and Ocholi (2008) expressed that deforestation proceeds at the rate of 67.27km^2 per annum in the northern flank of the study area while in the other southern section, the vegetation was described to be a formidable bio-geographic zone composed of different wildlife species (a host of grass, shrubs, savannah trees and forested areas that varies across space) but recently, species have been depleted largely forced by quest for developments on land.

2.2 Sediment Sampling

Twelve (12) sediment samples were collected at the upstream and downstream segments of the six tributaries (Ankpa, Obele, Adada, Oji, Mamu and Ezu) of the Anambra drainage basin (Fig. 1), amounting to twenty-four (24) sediment samples collected from the basin in the rainy and dry seasons within the months of July and December respectively in year 2015. These months are the peaks of rainy and dry seasons respectively when sediment fluxes are at their extreme conditions (height and lowest). One (1) kilogram of sediment was collected from the top surface layer (within 10 cm depth) of the sediments at each location using a Van Veen grab. The control sample was collected at the source of the drainage basin, and all sampling locations were tracked as shown in Fig. 1 using a GPS device. Sample from each location was carefully packaged in black polyethylene plastic bags to avoid microbial actions on sediments' components and properly labelled at the collection points for easy identification. The collected samples were transported within 48 hours of collection to the National Steel Raw Materials Exploration Agency, Kaduna, Nigeria for both geotechnical and geochemical analyses.

2.3 Laboratory Analysis

Sediments collected were analysed in the laboratory to ascertain the chemical composition and potential toxic metals - heavy metals. Soil was also analyzed to determine the physical properties - particle size distribution (PSD), bulk density and porosity using procedures outline by relevant standards.

The electron scanning microscope imaging was carried out on the dried bulk sediment samples. Thin slices of these natural sediments were prepared for imaging. Sample preparation and imaging were done carefully following the method developed by the Materials Analysis and Research Laboratory (MARL) at Iowa State University. To obtain an image, prepared samples coated with conductive (isopropanol based graphite) material were mounted on the sample holder in the SEM chamber, thus allowing the SEM to generate electrons from the sample.

The procedure of obtaining the total metal concentrations in sediment was based on the process draft by Ayogu *et al.* (2019b). The samples were oven-dried at 105 ºC, pulverized and sieved in a 2 mm mesh nylon sieve to remove retailed friable substances and coarse grains. Thereafter, the metallic concentrations of the prepared samples were investigated using Advant-X Thermoscientifics X-ray fluorescence spectrometer- model XRF 1200 ARL, with detention limit of 0.01 mg/kg. The pulverised samples are placed in the uncontaminated diffractometer and illuminated with X-rays to produce features (spikes) of atoms and elements present in samples on an automated recorder through a detector. Each metal's identification was from the energies of its characteristic radiation, while concentration evaluation was from intensity of measurements.

2.4 Data Analysis

The data which was generated from laboratory analysis (Table 1) was summarized statistically to presents their central and dispersion tendencies (Table 2). T-test comparative analysis was carried out on the data in order to determine if there are significant seasonal and lateral variations between the concentration level of PTEs in samples collected from both rainy and dry seasons and from upstream and downstream reaches respectively. All statistical data analysis, such as central and dispersion tendencies and the T-test comparative analysis were done with Microsoft Excel 2007. To facilitate the measurement of heavy metal enrichment and degree of contamination, basin's sediments and soil were subjected to various pollution and erosion risk assessments as shown in equation 1 – 7.

Pollution load index (PLI) aims to determine the number of times a metallic content in a sediment sample is in excesses against the background concentration value (Ayogu *et al.* 2019b). Therefore, PLI signifies the comprehensive toxicity of a sample with respect to heavy metals. The pollution load index proposed by Tomlinson *et al.* (1980) was calculated using equation 1.

$$PLI = (CF1 \; x \; CF2 \; x \; CF3 \ldots\ldots\ldots..CFn)1/n \qquad (1)$$

The PLI of the heavy metals were evaluated following the standard described by Lacutusu (2000; pp. 393-402).

Modified degree of contamination (*mCd)* in sediment by metals was calculated using equation 2 proposed by Likuku *et al.* (2013).

$$mCd = \frac{1}{N}\sum_{i=1}^{N} Cf_i \qquad (2)$$

Where *N* is the number of elements analyzed and *Cf*is the contamination factor calculated as shown in equation 3.

$$Cf = M_x / M_b \qquad (3)$$

Where *Cf* is an element contamination factor while M_x is the mean concentration of the element/ metal, and M_b is the baseline/ standard concentrations of the element or metal.

Contamination degree (CD) is the sum of *Cf* of all recorded metals at a particular sampling location. Ahdy and Kahled (2009) noted that, sediments could be classified into four grade rating, i.e., CD < 6, 6 ≤ CD < 12, 12 ≤ CD < 24 and CD ≥ 24 are rated class 1, 2, 3 and 4, signifying low, moderate, considerable and very high CD respectively.

The "ROM" scale, developed and named after the researchers- Roslan and Mazidah, was created in year 2001 to grade the degree of erosions tragedies using the basis of logical predictive calculation Abidin *et al.* 2017). The formation of the "ROM" Scale was centred simply on soil grading characteristics, meaning that erodibility index can be measured if the soil's textural composition of sand, silt and clay are known. The "ROM" Scale equation is given by Abidin *et al.* (2017) as seen in equation 4:

$$ROM = \frac{\% \, sand + \% \, silt}{2(\% \, clay)} \qquad (4)$$

The ROM scale has effectively been applied to river bank erosion risk assessment, and the grading scale for soil erosion risk classification has been noted by Abidin *et al.* (2017).

Other indices of erosion evaluated are dispersion ratio, mean weight diameter and aggregate stability. Sediments' dispersion ratio was determined following equation 5 as outlined by Igwe and Nkemakosi (2007).

$$DR = \frac{\%\,WDS + \%\,WDC}{\%\,total\ silt\ and\ clay} \qquad (5)$$

The mean weight diameter was calculated using the formula reported by Marquez *et al.* (2004) as shown in equation 6.

$$MWD = \sum_{i=1}^{n} \bar{x}iwi \qquad (6)$$

X_i is the mean diameter of each size fraction while w_i is the proportion of the total sample weight occurring in the size fraction.

Soil aggregate stability (SAS) was expressed in form of water stable aggregates (WSA) as proposed by Rohoskova and Valla (2004). The WSA of studied soil was determined following Marquez *et al.* (2004) as expressed in equation 7.

$$WSA\ (\%\ of\ soil > 250\mu m) = \frac{(weight\ of\ dry\ aggregate - sand)}{(weight\ of\ dry\ soil - sand)}\ x\ 100 \qquad (7)$$

3.0 Result and Discussions

3.1 Stream Sediments' Geochemical Composition

Potential toxic elements (PTEs) concentrations in sediments of the Anambra drainage basin are presented in Table 1 showing PTEs - Nickel (Ni), Manganese (Mn), zinc (Zn), Iron (Fe), Chromium (Cr), Scandium (Sc) and Europium (Eu), lead (Pb), Vanadium (V), Molybdenum (Mo) various concentration.

From the result analyses, the mean concentrations of Zn, Ni, Mn, Fe, Cr, Pb, V, Mo, Sc and Eu at the upstream in the rainy season are 2.1, 0.05, 4.05, 3.97, 0.02, 1.98, 0.1, 0.02, 0.003 and 0.01 mg/kg while concentrations at the downstream reach are 0.07, 0.03, 2.98, 5.52, 0.03, 1.83, 0.11, 0.02, 0.003and 0.01 mg/kg respectively (Table 2). The standard deviation of elemental concentrations in the rainy season for both upstream and downstream reaches ranges between 0.005 – 3.37 and 0.008 – 3.4 while skewness ranges from 0 – 2.03 and – 0.31 – 1.59

respectively (Table 2). During the dry season, however, the mean concentration of Zn, Ni, Mn, Fe, Cr, Pb, V, Mo, Sc and Eu recorded in sediments at the upstream changed to 5.33, 0.06, 2.05, 1.85, 0.03, 2.78, 0.12, 0.04, 0.007 and 0.03 mg/kg with standard deviation and skewness ranging from 0.005 – 3.49 and -2.15 – 2.4 while the downstream reach recorded 3.62, 0.05, 3.25, 1.32, 0.04, 2.98, 0.12, 0.04, 0.05 and 0.04 with standard deviation and skewness ranging between 0.005 – 3.25 and -2.49 – 1.33 respectively (Table 2).

However, at the source of the river sediments which serves as control sediment recorded the least PTEs level - below 0.01 mg/kg (Table 1). In other locations more concentration level was obtained suggesting possible accumulation and enrichment of sediments in the basin with potential toxic metals. Surficial fluvio-geomorphic processes on the local geology could be responsible for the accumulation of PTEs in the source sediments (Ayogu *et al.* 2019b).

From the result, PTEs followed a definite pattern in comparison between the rainy and dry seasons. The result reveals that with the exception of Mn and Fe, concentrations of PTEs generally increased in the basin's sediment in the dry season than the rainy season (Tables 1 & 2). Duncan *et al.* (2018) noted that excessive washing away of the surface sediments accounts for such lows in the rainy season. Ayogu *et al.* (2010b) suggested that the high Fe and Mn content in the rainy season's sediment is orchestrated by weathering and erosion of Fe-Mn rich rocks located within the basin. They also stressed that PTEs levels could be higher in dry due to re-deposition, settlement and absorption of PTEs-laden sediments and reduced self-purification function of rivers. Some PTEs (Mn and Pb) in rainy season were higher in upstream sediments than downstream (Table 2). This result is suggestive of increased erosion rate in due to higher run-off and anthropogenic activities such as farming and commercial activities, while increase in PTEs at the downstream sediments might be caused by re-deposition of PTEs washed from the upstream, making the downstream a sink for heavy metals.

However, some of the PTEs such as Ni and Zn decreased in concentration at the downstream compared to the upstream in rainy and dry seasons. This result disagrees with the general acceptable notion that PTEs' concentrations are often higher at the downstream than the upstream (Duncan *et al.* 2018). This could be attributed to the influence of constant sediment mining within the Anambra drainage basin, particularly during the dry season and reduced precipitation –cum- river discharge. The result of the standard deviation (SD) of the various PTMs identified in the sediments ranged between 0 – 3.49 for both seasons (Table 2), signifying that only a little difference existed between the sampled sediments. The result of the SD is in agreement with the computed skewness in PTEs' concentrations in sediments which range between -2.49 to 2.40 (Table 2).

Table 1: Sediments' PTMs' concentrations in rainy a season

Seasons	River	Location	Heavy metals (mg/kg)[a]									
	Sediment		Cr	Eu	Fe	Mn	Mo	Ni	Sc	Pb	V	Zn
Rainy	Ankpa	Upstream	0.04	0.02	1.2	1.8	0.02	0.05	< 0.01	1.8	0.09	< 0.01
		Downstream	0.02	< 0.01	1.2	1.8	0.02	0.04	< 0.01	2.0	0.09	< 0.01
	Obele	Upstream	0.01	0.02	8.1	9.1	0.01	0.06	< 0.01	1.7	0.01	< 0.01
		Downstream	0.04	0.02	1.1	2.1	0.01	0.03	< 0.01	1.9	0.13	< 0.01
	Adada	Upstream	0.02	0.01	1.2	1.8	0.01	0.04	0.001	1.8	0.09	< 0.01
		Downstream	0.02	0.03	8.0	4.0	0.01	0.02	0.01	1.9	0.11	< 0.01
	Oji	Upstream	0.02	0.01	6.3	5.8	0.02	0.03	< 0.01	2.1	0.12	1.9
		Downstream	0.03	< 0.01	7.2	1.9	0.02	0.03	< 0.01	1.6	0.09	1.9
	Mamu	Upstream	0.01	0.01	5.9	1.1	0.01	0.07	< 0.01	1.5	0.1	2.0
		Downstream	0.02	< 0.01	7.6	1.2	0.03	0.04	0.01	1.9	0.12	< 0.01
	Ezu	Upstream	0.04	0.01	1.1	4.7	0.05	0.02	0.01	3.0	0.11	8.7
		Downstream	0.03	0.02	8.0	6.9	0.01	0.03	< 0.01	1.7	0.09	2.3
	Control	River source	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	WHO[b]		50	-	28,000	600	-	25	-	23	-	88
Dry	Ankpa	Upstream	0.03	0.01	5.2	1.0	0.04	0.07	< 0.01	3.0	0.11	5.9
		Downstream	0.03	0.03	1.4	5.1	0.04	0.03	0.01	3.1	0.12	1.8
	Obele	Upstream	0.04	0.01	1.1	2.2	0.05	0.07	< 0.01	3.1	0.12	9.6
		Downstream	0.03	0.02	1.1	1.8	0.04	0.06	< 0.01	3.0	0.13	1.3
	Adada	Upstream	0.01	0.02	1.5	4.7	0.02	0.07	0.01	2.6	0.10	7.9
		Downstream	0.04	0.05	1.5	7.9	0.04	0.05	<0.01	3.1	0.10	7.6
	Oji	Upstream	0.03	0.05	1.1	2.2	0.05	0.07	0.01	3.1	0.13	2.7
		Downstream	0.04	0.02	1.6	2.2	0.04	0.06	< 0.01	2.9	0.13	8.0
	Mamu	Upstream	0.04	0.03	1.1	< 0.01	0.07	0.06	0.01	3.0	0.12	5.9
		Downstream	0.03	0.06	1.1	1.3	0.04	0.06	0.01	2.8	0.13	1.6
	Ezu	Upstream	0.03	0.05	1.1	2.2	0.03	0.03	0.01	1.9	0.13	< 0.01
		Downstream	0.04	0.03	1.2	1.2	0.03	0.05	0.01	3.0	0.10	1.4
	Control	River source	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01
	WHO[b]		50	-	28,000	600	-	25	-	23	-	88

[a]Maximum detection limit of the equipment used is 0.01 mg/kg [b] Relevant recommended background limit adapted from Duncan et al. (2018), - Connotes data not available

Table 2: Summary statistics of the chemical composition of the sediments

		Rainy season						Dry season								
Season	Parameter	N/O[a]	mean	SD[b]	max	min	skewness	N/O[a]	mean	SD[b]	max	min	skewness	p-value	a-value	Comparison
	Cr	6	0.02	0.01	0.04	0.01	0.52	6	0.03	0.01	0.04	0.01	-1.37	0.37	0.05	Not Sig.
	Eu	6	0.01	0.005	0.02	0.01	0.97	6	0.03	0.02	0.05	0.01	0.36	0.08	0.05	Not Sig.
	Fe	6	3.97	3.16	8.1	1.1	0.24	6	1.85	1.65	5.2	1.1	2.4	0.18	0.05	Not Sig.
	Mn	6	4.05	3.09	9.1	1.1	0.87	6	2.05	1.57	4.7	0	0.68	0.19	0.05	Not Sig.
Upstream	Mo	6	0.02	0.02	0.05	0.01	1.94	6	0.04	0.02	0.07	0.02	0.25	0.03	0.05	Sig.
	Ni	6	0.05	0.02	0.07	0.02	0	6	0.06	0.02	0.07	0.03	-2.15	0.13	0.05	Not Sig.
	Sc	6	0.003	0.005	0.01	0	0.97	6	0.007	0.005	0.01	0	-0.97	0.29	0.05	Not Sig.
	Pb	6	1.98	0.53	3	1.5	1.78	6	2.78	0.47	3.1	1.9	-1.76	0.02	0.05	Sig.
	V	6	0.1	0.01	0.12	0.09	0.67	6	0.12	0.01	0.13	0.1	-0.67	0.03	0.05	Sig.
	Zn	6	2.1	3.37	8.7	0	2.03	6	5.33	3.49	9.6	0	-0.53	0.13	0.05	Not Sig.
	Cr	6	0.03	0.008	0.04	0.02	0.86	6	0.04	0.005	0.04	0.03	0	0.06	0.05	Not Sig.
	Eu	6	0.01	0.01	0.03	0	0.33	6	0.04	0.02	0.06	0.02	0.81	0.02	0.05	Sig.
	Fe	6	5.52	3.4	8	1.1	-0.94	6	1.32	0.21	1.6	1.1	0.23	0.01	0.05	Sig.
	Mn	6	2.98	2.14	6.9	1.2	1.59	6	3.25	2.69	7.9	1.2	1.33	0.85	0.05	Not Sig.
Downstream	Mo	6	0.02	0.008	0.03	0.01	0.86	6	0.04	0.004	0.04	0.03	-2.45	0	0.05	Sig.
	Ni	6	0.03	0.008	0.04	0.02	-0.31	6	0.05	0.01	0.06	0.03	-1.59	0.006	0.05	Sig.
	Sc	6	0.003	0.005	0.01	0	0.97	6	0.005	0.005	0.01	0	0	0.6	0.05	Not Sig.
	Pb	6	1.83	0.15	2	1.6	-0.84	6	2.98	0.12	3.1	2.8	-0.67	0	0.05	Sig.
	V	6	0.11	0.02	0.13	0.09	0.49	6	0.12	0.01	0.13	0.1	-0.71	0.19	0.05	Not Sig.
	Zn	6	0.7	1.09	2.3	0	1.03	6	3.62	3.25	8	1.3	0.96	0.06	0.05	Not Sig.

[a] N/O signifies number of observations [b] SD indicates standard deviation

These values could imply that the same sources or similar sources and processes are accountable for the enrichment of PTMs in sediments of the Anambra drainage basin. The general order of PTEs occurrence in the sediments are Fe >Mn> Zn >Pb>>> V > Cr > Ni > Mo >Eu>Sc while Rivers Adada and Ankpa recorded the highest and lowest levels of PTEs concentrations traceable to anthropogenic activities.

3.2 Sediment Pollution Assessment

In order to evaluate sediment quality in the Anambra drainage basin, PTEs' concentration levels of different parameters- PLI. mCd and CD were compared with internationally-World Health Organization standard (Table 1 & 3).

Table 3: Pollution indices of the Anambra drainage sediments

Location	Environment	PLI	mCd		CD	
			Rainy	Dry	Rainy	Dry
Ankpa	Upstream	0.54	0	25.80	9.1	52.43
	Downstream	0.27	9.02	20.01	18.23	40.96
Obele	Upstream	0.67	34.12	26.80	68.53	60.02
	Downstream	4.15	9.47	12.71	19.08	26.3
Adada	Upstream	0.06	8.75	28.04	17.68	59.96
	Downstream	0.73	25.44	34.21	50.97	72.16
Oji	Upstream	0.66	28.62	15.89	57.37	33.59
	Downstream	0.29	22.60	24.71	45.34	53.1
Mamu	Upstream	1.34	18.71	16.97	37.75	37.89
	Downstream	0.24	19.78	12.09	39.75	25.26
Ezu	Upstream	0.36	28.96	9.66	58.02	19.31
	Downstream	0.61	33.65	12.03	67.44	24.91

The PLI analysis showed that sediments in the Anambra drainage basin are at various levels of contamination and pollution. The results revealed PLI ranged between 0.66 – 1.34 and 0.24 – 4.15 (Table 3), signifying very slight contamination to slight pollution and slight contamination to severe pollution at the upstream and downstream reaches respectively (Table 4). This implies that the downstream is more vulnerable to PTEs enrichment. With PLI > 1, River Obele downstream is the most affected with severe pollution (PLI > 4) while River Mamu upstream revealed evidence of slight pollution (PLI > 1) as shown in Table 3:

Table 4: Contamination and pollution grading standards

	PLI range
Very slight contamination	< 0.1
Slight contamination	0.10 - 0.25
Moderate contamination	0.26 - 0.5
Severe contamination	0.51 - 0.75
Very severe contamination	0.76 - 1.00
Slight pollution	1.1 2.0
Moderate pollution	2.1 - 4.0
severe pollution	4.1 - 8.0
Very severe pollution	8.1 - 16.0
Excessive pollution	> 16.0

Sediments from Ankpa, Obele and Oji upstreams and Ezu downstream had severe contamination status with PLI between 0.54 and 0.73 (Table 3 and 4). Sediments from Obele, Adada and Mamu possess higher PTEs pollution (higher PLI) due to the agricultural and commercial activities within the regions while Anpka had the least concentration of PTEs because it is the drainage source (Table 3).

The overall contamination degree (CD) of sediments in the Anambra drainage basin is presented in Table 3. At the upstream and downstream in the rainy season, CD was evaluated to range from 9.1 – 68.53 while at both reaches (upstream and downstream) in the dry season, CD measure up to 17.31 – 72.16. Therefore, all sediments in the basin could be classified either as class 3 or class 4, implying that the sampled sediments possess considerable CD to very high CD. The mCd results agree with the CD, suggesting that sediments of the basin suffer from high contamination. The mCd for rainy season's sediments range between 0 – 34.12 (Table 3), implying no contamination to ultra-high contamination of sediments (Table 5) while mCd for the dry season suggests that sediments contain very high degree of contamination to ultra-high contamination with values ranging from 9.6 – 34.21 (Table 3 & 5).

Table 5: Modified degree of contamination classification and description

mCd Classes	Modified degree of contamination level
mCd< 1.5	Nil to very low degree of contamination
1.5 ≤ *mCd*< 2	Low degree of contamination
2 ≤ *mCd*< 4	Moderate degree of contamination
4 ≤ *mCd*<8	High degree of contamination
8 ≤ *mCd*< 16	Very high degree of contamination
16 ≤ *mCd*< 32	Extremely high degree of contamination
mCd≥ 32	Ultra-high degree of contamination

3.3 Sediment and Pollution Sources

Local geology, erosion and anthropogenic activities influence the accumulation of sediments and PTEs in Anambra drainage basin. Shale and mud-rocks dominates the lithology of the basin (Fig. 2) and they have the potential of absorbing and storing PTEs thereby performing a reservoir function (Aprile and Bouvy 2008). With regard to soil, fine particles such as silt, clay and colloidal materials are generally surface-active and have Fe/Mn oxide in association, which can contribute to the deposition of metals. This agrees with the high Fe and Mn in the sediments (Table 1 & 2). Thus, geology of the basin profoundly affects sediment deposition and accumulation of PTEs. Furthermore, the decimation of the basin terrain by soil erosion leads to sedimentation of basin. Within the basin, the classical erosion sites exist in the False-bedded Ajali Sandstone, Nanka and Ameki Sands and coastal plain sands (Fig. 2).

Table 6 presented some physical properties of soils - particle size distribution PSD, bulk density and porosity. The PSD analysis reveals that soil from the rainy season contained sand between 72 – 88% with average of 79.5 % and silt/ clay between 12 – 28% with average of 20.5 %, while the dry season soil possessed sand within 71 – 89 % and silt/ clay between 11 – 29 % with averages of 79 and 21 % respectively. High sand content in these soils is associated with the preferential removal of clay and silt by erosion, which are the main carrier of PTEs. However, high sediment mining within the basin accounts for the very low PTEs concentration in sediments when compared to WHO standards (Table 1) thus, corroborating Singh *et al.* (2017b); Ayogu *et al.* (2019b); Duncan *et al.* (2018); Aprile and Bouvy (2008) findings.

The soils' bulk density (ρt) in both rainy and dry seasons ranges from 1.17 – 1.58and 1.35 – 1.71 g/cm^3 respectively (Table 6).

Table 6: Anambra basin materials' physical and erosion indices characterization

Season	Sub-basin	Clay (%)	Silt (%)	FS (%)	CS (%)	TS (%)	ρt (g/cm^3)	n (%)	MWD (mm)	AS (%)	DR	ROM	Textural class
Rainy	Ankpa	15	9	18	70	88	1.55	56.6	0.65	11.74	0.54	3.23	LS
	Obele	8	9	21	60	81	1.57	40.75	0.86	23.46	0.54	5.63	LS
	Adada	5	10	12	71	83	1.58	40.38	0.62	20	0.54	9.3	LS
	Oji	12	18	20	52	72	1.58	40.38	1.18	17.79	0.55	3.75	SL
	Mamu	20	13	24	54	78	1.37	48.3	0.93	19.66	0.54	2.28	SCL
	Ezu	25	24	34	41	75	1.17	44.28	1.0	24.79	0.39	1.98	SCL
Dry	Ankpa	7	8	13	69	82	1.61	49.06	0.66	9.17	0.61	6.43	LS
	Obele	8	5	10	74	84	1.71	33.47	0.93	23.16	0.61	5.56	LS
	Adada	7	6	8	81	89	1.66	37.38	0.68	21.12	0.56	6.79	LS
	Oji	11	10	17	60	77	1.63	38.35	1.32	27.4	0.58	3.95	LS
	Mamu	8	12	13	58	71	1.58	40.38	0.13	21.89	0.56	5.19	LS
	Ezu	10	15	29	42	71	1.35	19.25	10.54	27.55	0.42	4.3	SCL

FS = Fine sand, CS = Coarse sand, TS = Total sand, ρt = Bulk density, n = porosity, MWD = Mean weight diameter, AS = Aggregate stability, DR = Dispersion ratio, LS = Loamy sand, SL = Sandy loam, SCL = Sandyclay loam

Nandi and Luffman (2012) reported that ρt of non-erodible ultisols soils ranged from 1.22 - 1.50 g/cm^3 while in erodible soils ranged between 1.16 - 1.35 g/cm^3. Soil porosity (n) was observed higher in erodible soils than for the non-erodible soils (Nandi and Luffman 2012). This agrees with the results of the present study where rainy season's soils recorded porosity range of 40.38 – 56.60 % which is significantly greater than 19.25 – 49.06 % registered in the dry season soils. These results suggest that erosion is most likely to occur during the rainy season than the dry season, thus initiating greater sediment and PTEs supply and accumulations during the rainy season.

Other soil indices such as DR, MWD and AS that are reliable in erosion potential analyses were evaluated (Table 6). All the indices evaluated showed low values with DR ranging between 0.39 – 0.61 while MWD ranged from 0.13 – 10.54 mm and AS measuring between 9.17 – 27.55 %. These values are low, and highlighted low resistant nature of the basin's geological materials to agents of erosion. This is attributed to abundant coarse sand (Table 6) which exposes soils to increased rate of detachability, thus the soil more vulnerable to erosion. Moreover, the result of the ROM presented in Table 6 when compared with the ROM scale suggested that 42% soils in the drainage basin are moderately erodible while 50% and 8 % are highly and very highly susceptible to erosion respectively (Table 7). Therefore, geology of the basin and erosion are major contributors of sediments and PTEs to the river channels (Aprile and Bouvy 2008). Table 7: The ROM Scale (Abidin and Mukri, 2002)

Soil erodability category	ROM Scale	Present study
Low	< 0.5	nil
Moderate	1.5 - 4.0	42%
High	4.0 - 8.0	50%
Very high	8.0 - 12.0	8%
Critical	> 12.0	nil

On the other hand, many anthropogenic activities (dams and conduits) as seen in Plate 1a could be controlling factors of some flowing rivers and thus could be great contributors of PTEs discharged into sediments in river channels (Singh *et al.* 2017a, b). Also, potential toxic elements generated by many human activities find their way into river channels annually through erosion.

Plate. 1: Anthropogenic activities within the basin

Moreover, the contamination factor (Cf) and enrichment factor (Ef) analyses of Ayogu*et al.* (2019b) on the basin's sediment suggested that human activities like agriculture and domestic waste disposal (Plate. 1b), industrial waste (Plate. 1c), construction and hazard (flood and erosion) control measures (Fig. 3a) are major factors escalating PTEs' levels in the sediments.

3.4 Sediment Outsourcing

` Mining and use of river sediments within the Anambra drainage basin is a precipitate of scarcity of engineering resources. Apart from the Ajalli Sand, sources of sharp sands for engineering constructions within the basin are not many. River sediments became a close substitute for the scarce construction sand. The river sediments were scanned and evidences from SEM imaging have shown that sediments contain high amount of quartz which is a stable mineral and component of sand (Plate 2), and thus rationalize why the sediments are intensively used as construction materials. Thus, corroborating our findings is (Rout *et al*. 2013), who posited that angularity of particle may suggest high angle of internal friction between the particles, which culminate in moderate to high frictional strength of the construction materials.

The PTEs entering into river channels are stored in sediments in various ways such as adsorption onto suspended particulate matters, flocculation and sedimentation (Singh *et al.* 2017a; Zhang *et al.* 2018). However, the occurrence of PTEs in sediments, for instance lead (Pb) raises concern on the continuous use of these sediments, bearing in mind that these PTEs are very toxic when ingested in any form and allowed to accumulate in the body over a long period of time.

Season and location of mining also affects the quality and usability of mined sediments. The average concentration of PTEs increased from rainy season to dry season in both reaches of the rivers. However, at both the upstream and downstream, 3 (Mo, Pb and V) and 5 (Eu, Fe, Mo, Ni and Pb) respectively had their increment in the dry season statistically significant ($p \leq 0.05$) as seen in Table 2. This suggests that seasonality is a significant factor controlling PTEs' accumulation and enrichment in sediments. This implies that further degradation of sediments occurs during the dry seasons due to lower river discharge, particulate settlement and sedimentation (Singh *et al.* 2017a; Zhang *et al.* 2018). A similar comparison between the upstream and downstream for both seasons suggested that all changes (increase or decrease) were statistically insignificant ($p \geq 0.05$), thus suggesting inconsistency in such changes possibly due to similarity in controlling factors of PTEs’ accumulation or as a result of sediment mining in both river reaches.

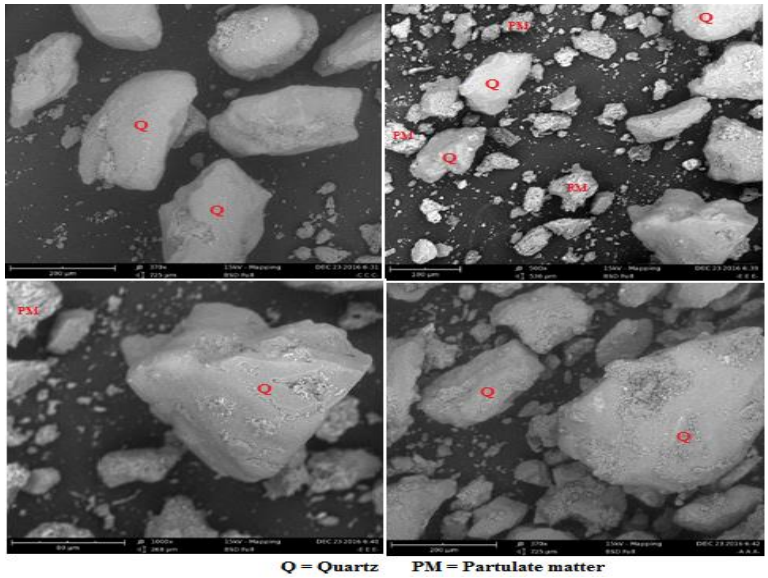

Plate 2: SEM photographs of the studied sediments.

However, three (3) significant additions in PTEs’ level in the upstream against five (5) in the downstream (Table 2) may suggest better sediment quality at the upstream than the downstream. Therefore, we suggest that sediment mining in the Anambra drainage basin is best done at the upstream during the rainy season.

3.5 Environmental Implications

Mining and usage of sediments in Anambra drainage basin as engineering materials have extensive environmental implication because of contaminant loading. This practice would have contaminants introduced into new areas of the environment and bring contaminants in close proximity with human, thus increasing health risk (Singh *et al.* 2017a). Ingestion and excess accumulation of these PTEs in the body over a long period of time have toxic effects on plants and animal lives, and at times, carcinogenic in human.

At certain conducive conditions (low pH and high temperature), PTEs becomes soluble and re-enter the overlying water (Singh *et al.* 2017a; Zhang *et al.* 2018 Duncan *et al.* 2018; Atkinson *et al.* 2007), thus reducing surface water quality and rendering the water unsuitable for human uses. However, a study has shown that physical disturbances release metals more rapidly into water than biological disturbances (Atkinson *et al.* 2007). Carrying out irrigation with the contaminated water pollute surface soils, increase soil and crop toxicity (Singh *et al.* 2017a) and reduce soil geotechnical properties (Vega *et al.* 2004; He *et al.* 2005) such as shear strength and durability (Ivan and Ikuo 2011), soil stabilization (Yan-Yun *et al.* 2004), soil workability (Barisic *et al.* 2017; Gomes and Pinto 2006) as well as specific gravity and optimum water content (Aprile 2004).

Sediment mining may increase erosion risk within the basin via widening and deepening of river channels. Deeper river channels increase river discharge causing erosion of banks and beds, which invariably increases PTEs in sediments and surface water. On the other hand, such action can trigger sediment deposition, which consequently enhances PTEs accumulation and sedimentation that threatens the existence of many rivers. Therefore, the practice of sediment mining disrupts the natural course and balance of a river, thereby, negatively impacting aquatic and human lives as a result of poor sediment quality.

4.0 Conclusions

In this study we noted that sediments in the Anambra drainage basin contain PTEs such as Zn, Ni, Mn, Fe, Cr, Pb, V, Mo, Sc and Eu. Although the PTEs' levels in the sediments are below WHO recommended standard, evidences from CD, mCd and PLI demonstrated that the sediments are at various degrees of contamination. It ranged from slight contamination to severe pollution which could impact on basin ecology and human negatively.

The PTEs' contents in the sediments are attributed to both natural and anthropogenic influences on the basin environment. The basin soils' physical properties such as PSD, porosity and bulk density as well as erosion risk indices (AS, MWD, DR and ROM) revealed that weathering and erosion are major contributing factors in sediment and PTEs' accumulations. This is largely forced by high rainfall and run-off experienced in the region, and coupled with the unconsolidated soil which predominate the basin. Anthropogenic activities were major culprit in accumulation of PTEs in sediments. Experimental results also revealed that there are significant differences in PTEs' concentrations between seasons, and therefore highlighting seasonality as a controlling factor in PTEs' enrichment in sediments. Results suggested that there is worst degree of contamination of sediment in the dry season than the rainy season which is statistically significant irrespective of what part of the river (upstream or downstream) reaches.

Finally, the authors wish to recommend that sediment mining should be discouraged to maintain balance between the drainage basin and the environment. Also, proper monitoring of sediments and land use by constituted basin authorities should be regular to address and forestall further accumulations of sediments and PTEs in the Anambra drainage channels which threaten public health, environmental safety and drainage existence within the basin.

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