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Ecological Risk Assessment of Selected Elements in Sediments from Communities of the River Nun, Bayelsa State, Nigeria

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Abstract

The ecological risks of some fractionated toxic elements (Pb, Cu, Cr, Cd, Zn and Ni) were assessed in sediments from communities around the river Nun in the Niger Delta region of Nigeria. Mean value of secondary data (contaminated and control area) was used to calculate the ecological risk following standard protocol. The resulting values were compared with standards. Results of contamination factors of study metals revealed moderate contamination, all other heavy metals were uncontaminated except for Cu and Ni which depicted an index of geo-accumulation from not contaminated to moderately contaminated, potential ecological risk index showed low ecological risk. Apart from Cr and Zn which revealed low sum of pollution index all other metals ranged from moderate to high sum of pollution index. The Pollution Load Index (PLI) showed deterioration of site quality with values greater than 1. However, results of the sum of pollution index and pollution load index may not be limited to activities of the numerous oil and gas activities especially from makeshift refineries and bunkery in the vicinity of the river. Indiscriminate and uncontrolled discharge of municipal wastes may be another potential source of heavy metals.

Keywords: Heavy metals; Contamination factor; Index of geo-accumulation; Potential ecological risk index; Sum of pollution index; Pollution load index; River Nun;

Introduction

As a result of the exploitation and exploration of crude oil and natural gas, the ambient environment receives loads of human and industrial effluents which may be detrimental to the health of its inhabitants (Inengite et al., 2010). Consequent upon this is the resultant discharge of waste and process water washings. In a country like Nigeria, where the emission and disposal of all sorts of wastes into the environment is not monitored, the contribution of heavy metals pollutants to the environment by anthropogenic sources is overwhelming, hence, repeated evaluation of the pollution status of the environment especially the soil is imperative (Nriagu et al., 1988). According to Amnesty International's report, Shell has been responsible for 1,427 of the oil spills since 2007. The report also looks at the Nigerian Agip Oil Company, a subsidiary of the Italian Company ENI, which, it claims, has been another persistent culprit. From the start of 2013 to the end of September, Agip recorded 471 spills compared to Shell's 138, though the volume of Shell's spills far exceeded Agip's at 16,000 barrels compared to Agip's 4,000 (TAP, 2013). An estimated 9 million – 13 million (1.5 million tons) of oil has been spilled into the Niger Delta ecosystem over the past 50 years; 50 times the estimated volume spilled in the Exxon Valdez oil spill in Alaska 1989 (FME, NCF, WWF, UK, CEESP-IUCN 2006).The Niger Delta has a complex and extensive system of pipelines running across the region and large amounts of oil spill incidences have occurred through the pipelines and storage facility failures which may be caused by material defect, pipeline corrosion, soil erosion or sabotage. The Department of Petroleum Resources contends that 88% of the oil spill incidences are traceable to equipment failure, main causes of oil spills in the Niger Delta are vandalism, oil blowouts from the flow stations, accidental and deliberate releases and oil tankers at sea (Nwilo and Badejo, 2004, 2005a,b). Additionally, oil spills occur when the carrier pipelines are not regularly checked and maintained on a routine basis in such manner as to ensure that their protective coatings have not undergone wear.

One of the major constituent of the soil majorly impacted by wastes is heavy metals composition (Izah et al., 2017a-c, 2018). Heavy metals are metals and metalloids which are stable and have density greater than 5g/cm3 (Izah and Angaye, 2016; Izah et al., 2016; Izah et al., 2017d; Idris et al., 2013; John and Duffus, 2002; Tamunobereton-ari et al., 2010).They have also been defined based on density, some on atomic number or atomic weight; and some on chemical properties or toxicity (John and Duffus, 2002). Presently, heavy metal is a major source of concern to human health and the environment (Hassan et al., 2016). This could be due to the toxic effect they pose in biological organisms and the food chain. Heavy metals concentration in soil is usually higher within their top most regions (Wei and Yang, 2010; Mazurek et al., 2017). The presence of metals in sediment provides one of the largest storage of such within the river system (Peng et al., 2009). Furthermore, sediments conserve important environmental information and are increasingly recognized as both carrier and possible source of contaminants in aquatic systems (Gungun and Ozturk, 2001).

Some past spills have led to the complete relocation or loss of some communities, ancestral shrines and homes, potable drinking water, forest and agricultural land, and most significantly is the loss of fishing grounds and fish population, which is the major source of income for the Niger Delta people (Kadafa, 2012). Particularly, the inter-tidal nature of the nun river results in the intermittent washing ashore of pollutants and the continuous redistribution of run offs from nearby agricultural farmlands.Several studies have been conducted on water quality of Nun River in Bayelsa state. But most of these studies mainly focused on general physicochemical parameters (Ogamba et al., 2015; Agedah et al., 2015) and microbial quality (Seiyaboh et al., 2017; Agedah et al., 2015). Furthermore heavy metals (Aigberua et al., 2017) and microbial characteristics (Kigigha et al., 2018) have been reported in Nun River system. Aigberuaand Tarawou (2018), Aghoghovwia et al. (2018) reported heavy metals in sediment of river Nun. But information about the environmental risk assessment appears scanty in literatures.Therefore

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it has become imperative that the ecological risk assessment of heavy metals in bottom sediments within the river systems of the Niger Delta region of Nigeria be evaluated using several pollution indices which include the contamination factor, index of geo-accumulation, potential ecological risk index and sum of pollution index. The intention of this study is to evaluate the potential environmental impact or risk of heavy metals availability within the aquatic ecosystem by applying theoretical pollution indices modules.

Methodology

Study Area

The river Nun is one of the major navigable channels of the Niger Delta region and one of the bifurcations of the Niger River course. The river flows for about 160 km south to the Gulf of Guinea and empties into the Atlantic Ocean at Akassa. The river course flows through sparse settlements and swamps (Encyclopaedia Britannica, 2013). The main course of the river lies between the coordinates of latitude 5.298847°N and longitude 6.414350°E and plays host to numerous oil and gas installations and illegal oil refineries.The samples were collected around numerous communities including Peremabiri, Otuan, Akpobeleiowei, Letughene, Ogboinbiri, Yenagoa, Otuoke, Oloibiri, Amassoma and Sagbama. While the control points were located about 2km away from the Sagbama community and it's environ.Like other regions within the Niger Delta, two predominant climatic conditions depict the area including dry season (November to March) and wet season (April to October). The region is characterized by relative humidity and temperature of 50 – 95% and 30 ± 7oC respectively all year round (Izah et al., 2017a-c, 2018; Aigberua et al., 2016).

Data source

Secondary data was used for this study. Data obtained for sediment samples collected from two (2) control points were compared against those from the contaminated areas across twelve (12) sampling points within the river system as previously published by Aigberua and Tarawou (2018). The overall mean of the contaminated and control areas of the published work of Aigberua and Tarawou (2018) was summarized and presented in Table 1. The baseline data obtained for the control point sediments represent the maximum amount of that element in a naturally undisturbed environment beyond which the environment is considered polluted with the test elements (Puyate, 2007; Aigberua et al., 2017). Furthermore, several mean have been used to calculate environmental risks of heavy metals including median, geometric mean of contaminated areas (Izah et al., 2017a-c; 2018) and arithmetic mean of the control area. Therefore,the control data was used for the assessment of the ecological risk of heavy metals in bottom sediments of the Nun river system. The predominant heavy metals considered for the study include Pb, Cu, Cr, Cd, Zn and Ni. The perceptual mapping of heavy metals distribution across the Nun river system is presented in Figure 1. [Table 1]

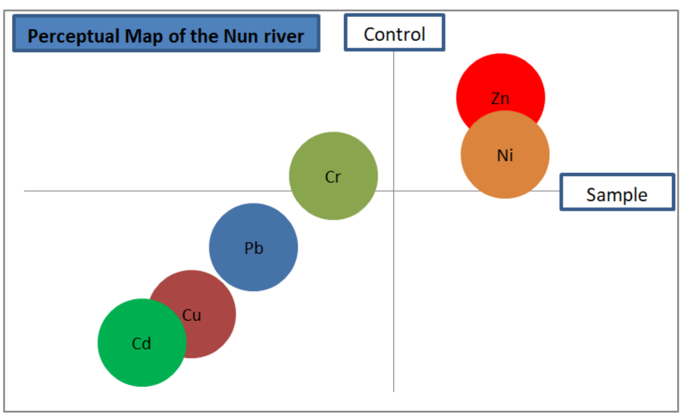

Figure 01: Perceptual mapping of heavy metals distribution across the Nun river system

Heavy metal pollution indices (HMPI)

Based on the data (Table 1), pollution indices model calculations that have been employed to assess the impact of anthropogenic inputs, and how they alter the concentration and distribution of toxic heavy metals across bottom sediments were assessed for the Nun river system. The following heavy metal pollution indices were applied: (i) Contamination factor (Ci_f), (ii) Potential ecological risk index (Ei_r), (iii) Index of geo-accumulation, and (iv) Sum of pollution index.

Table 1: Mean heavy metal concentrations across various locations and control pointS

Heavy Metals	Sample points	Control points	DPR Limit
Lead, Pb (mg/kg)	5.84	5.18	85
Copper, Cu (mg/kg)	2.90	1.84	36
Chromium, Cr (mg/kg)	9.62	8.75	100
Cadmium, Cd (mg/kg)	0.55	0.42	-
Zinc, Zn (mg/kg)	17.56	12.68	140
Nickel, Ni (mg/kg)	17.78	9.82	35

Modified from Aigberua and Tarawou (2018)

Contamination factor (CF)

The contamination factor as suggested by Hakanson (1980) has been used to describe the contamination of a given toxic substance in a lake or sub-basin where $Ci_f = Ci_{0-1}/Cin$ where Ci_{0-1} is the mean content of the substance and Cin is the pre-industrial reference level. The degree for expressing the contamination factor can be described as: $Ci_f < 1$, low contamination factor; $1 \le Ci_f < 3$, moderate contamination factors; $3 \le Ci_f < 6$, considerable contamination factors; and $Ci_f \ge 6$, very high contamination factor.

Potential ecological risk index (PERI)

An ecological risk factor or index (Eri) to quantitatively express the potential ecological risk of a given contaminant also suggested by (Hakanson, 1980; Xu et al., 2008) is $Er_i = Tr_i \, xCi_f$; where Tri is the toxic response factor for a given substanceviz: Pb = Cu = 5, Cd = 30, Cr = 2, and Zn = 1 (Hakanson, 1980), Ni = 5 (Izah et al., 2018; Xu et al., 2008; Soliman et al., 2015; Bhutiani et al., 2017; Izah et al., 2018), and Cif is the contamination factor. The following terminologies are used to describe the risk factor: $Er_i < 40$, low potential ecological risk; $40 \le Er_i < 80$, moderate potential ecological risk; $80 \le Er_i < 160$, considerable potential ecological risk; $160 \le Er_i < 320$, high potential ecological risk; and $Er_i \ge 320$, very high ecological risk.

Index of geo-accumulation (I-GEO)

The index of geo-accumulation proposed by (Muller, 1979; Muller, 1981) has been used to determine and define metal contamination in sediments from Kolo creek in the Niger Delta (Inengite et al., 2010). Geo-accumulation index serves to assess contamination by comparing current and pre-industrial concentration of heavy metals (Muller, 1979; Muller, 1981). Heavy metal concentration of a geographically similar unaffected plot was used as control and its values expressed as the pre-industrial reference levels, similar to the work of (Pam et al., 2013). It can be calculated using the equation: $IGEO = \log_2[C_i/(1.5C_b)]$ where Ci is the measured concentration of the examined metal i in the sediment, and Cb is the geochemical background concentration or reference value of the metal i and the factor 1.5 is used because of possible variations in background values for a given metal in the environment.

The geo-accumulation index (IGEO) was distinguished into seven classes by Muller: IGEO ≤ 0, class 0, practically uncontaminated; 0 <IGEO ≤ 1, class 1, uncontaminated to moderately uncontaminated; 1 <IGEO ≤ 2, class 2, moderately contaminated; 2 <IGEO ≤ 3, class 3, moderately to heavily contaminated; 3 <IGEO ≤ 4, class 4, heavily contaminated; 4 <IGEO ≤ 5, class 5, heavily to extremely contaminated; and 5 <IGEO<6, class 6, extremely contaminated (Muller, 1981).

Sum of pollution index (SPI)

Sum of pollution index is classified as integrated indices that serve as indicators for calculating the contamination of more than one metal. Consequently, this can be referred to as a bulk property. It can be defined using the formula SPI = ∑Pi where Pi is the single pollution index of heavy metal i, and m is the count of the heavy metal species (6 in this study). Soil and sediment quality assessment by heavy metals have been previously studied (Hakanson, 1980; Kwon and Lee, 1998).The degree of contamination (Cd), defined as the sum of all contamination factors is used to describe the contamination degree as $C_d < m$, low degree of contamination; $m \le C_d < 2m$, moderate degree of contamination; $2m \le C_d < 4m$, considerable degree of contamination; and $C_d > 4m$, very high degree of contamination (Caeiro et al., 2005; Pekey et al., 2004).

Pollution load index (PLI)

Pollution load index (PLI) as developed by Tomlinson et al. (1980), being earlier adopted by Mohamed et al. (2014), Izah et al. (2017b) and applied to evaluate the extent of metal pollution across each sampling point within the river system (table 1). The mathematical expression:

$$PLI = (PI_1 * PI_2 * PI_3 * \ldots\ldots\ldots PI_n)^{1/n}$$

Where n is the number of metals evaluated (6 in this study) and PI is the pollution index.

$PI = C_n/Cb$, where, Cn is the mean content of metals from at least five sampling sites and C_b is the pre-industrial concentration of individual metal. The PLI provides simple but comparative means for assessing a site quality, where a PLI < 1 depicts perfection; PLI =1 depicts that only baseline levels of pollutants are present and PL > 1 would indicate deterioration of site quality. [Table 2]

Results and Discussion

All heavy metals in this study revealed moderate contamination factor for bottom sediments of the river Nun. This was contrary to an earlier assessment of two auto mechanic workshops by Pam et al. (2013) where a considerable to very high contamination factor was observed for Pb and Cu. Overall, the heavy metal contamination factors for the Nun river depicted the following trend: Cr <Pb< Cd < Zn < Cu < Ni (Table 2).

Likewise, heavy metals in sediments revealed low potential ecological risk factor (Table 2) with Cd reflecting the most significant PERI value of 39.60. Generally, potential ecological risk index depicted the trend: Zn < Cr <Pb< Cu < Ni < Cd (Table 2).

Bottom sediments of the Nun river system mostly revealed a geo-accumulation index of the class 0 category for heavy metal accumulation (that is, uncontaminated), apart from Cu and Ni which revealed uncontaminated to moderately contaminated. Test metal levels depicted the trend Cr <Pb< Cd < Zn < Cu < Ni (Table 2). This study revealedl ower IGEO values when compared to earlier reports by Mohamed et al. (2014)

Table 2: Heavy metal pollution indices of heavy metals in the Nun river system

Heavy metal	Contamination factor, CF	Index of geo-accumulation, IGEO	Potential ecological risk index, PERI	Sum of pollution index, SPI	Pollution load index, PLI
Pb	1.13	-0.41	5.65	6.78	1.37
Cu	1.58	0.08	7.90	9.56	
Cr	1.10	-0.45	2.20	3.30	
Cd	1.32	-0.19	39.60	40.92	
Zn	1.38	-0.12	1.38	2.76	
Ni	1.81	0.27	9.05	11.13	
Pollution indices (HMPI)	i.)CF<1=low CF; ii)1≤CF<3=moderate CF; iii)3≤CF<6=considerable CF; iv)CF≥6=very high CF	i)IGEO≤0=uncontaminated; ii)0<IGEO≤1=uncontaminated to moderate contamination; iii)1<IGEO≤2=moderate contamination; iv)2<IGEO≤3=moderate to heavy contamination; v)3<IGEO≤4=heavy contamination; vi)4<IGEO≤5=heavy to extreme contamination; vii)5<IGEO≤6=extreme contamination	i)E_r<40=low PERI; ii)40≤E_r<80=moderate PERI; iii)80≤E_r<160=considerable PERI; iv)160≤E_r<320=high PERI; v)E_r≥320=very high PERI	i)C_d<m=low SPI; ii)m≤C_d<2m=moderate SPI; iii)2m≤C_d<4m=considerable SPI; iv)C_d>4m=high SPI	i)PLI<1=perfection; ii)PLI=1: only baseline levels of pollutants present ii)PLI>1=deterioration of site quality

where higher IGEO values were reported for soils close to phosphate fertilizer plant in Egypt. Also, this study contradicted earlier reports by Inengite et al.(2010) where Pb, Ni, Cr and V depicted non-pollution on the index of geo-accumulation scale. However, the result of this study showed slight similarity of trend with cassava mill effluent contaminated soil as reported by Izah et al. (2017c)

Apart from chromium and zinc which depicted low sum of pollution indices all other heavy metals ranged from moderate to high degree of contamination. The heavy metals being studied depicted the following trend: Zn < Cr <Pb< Cu < Ni < Cd (Table 2).

The Pollution Load Index (PLI) revealed a deterioration of site quality based on the observed degree of contamination which exceeded the value of 1. PLI values of this study compared to that of Mohamed et al. (2014).

The perceptual mapping of the spatial distribution of heavy metals across the Nun river was pictorially represented (Figure 1); this was used to portray a vivid pictorial representation of the spread of the test metals across the sampling points. Generally, the order of metal distribution revealed the following trend: Zn > Ni > Cr >Pb> Cu > Cd (Figure 1). Additionally, test metals were reported below the DPR permissive limit for standard sediment environment.

Conclusion

This study assessed the ecological risk of selected elements across spatial distributions in bottom sediments of the Nun river which is located in the Niger Delta region of Nigeria. The associated ecological risk index of heavy metals (viz: Pb, Cu, Cr, Cd, Zn and Ni) is an indicator that the Nun river is been threatened by the load of anthropogenic inputs to which it is subjected. The deterioration of site quality as revealed by the Pollution Load Index (PLI) further substantiates this standpoint. However, the significant pollutant load in the river may not be limited to activities of the numerous oil and gas companies in the region as the river is also prone to the indiscriminate and uncontrolled discharge of municipal wastes and the activities of illegal oil refineries along some of its estuaries. Even though the level of contaminating activities in the river is not yet threatening to consume the natural resources of the aquatic ecosystem, adequate measures must be taken to forestall the occurrence of oil spills as the network of numerous carrier pipelines underwater threaten to become future time-bombs if not regularly checked and maintained on a routine basis.

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