International Journal of Ecology and Environmental Sciences
www.ecologyjournal.in
Online ISSN: 2664-7133, Print ISSN: 2664-7125
Received: 22-01-2023, Accepted: 06-02-2023, Published: 24-02-2023
Volume 5, Issue 1, 2023, Page No. 15-21

Ecological and human health vulnerability of heavy metals from soku creek sediment

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Abstract

This study was conducted to determine some heavy metal concentration, sediment quality, ecological and human health risks in surface sediments from five (5) stations in Soku Creek label as SES1, SES2, SES3, SES4 and SES5. Four (4) different types of indices were employed for the evaluation of sediment quality which include Geo-accumulation Index (Igeo), Enrichment Factor (EF), Contamination Factor (CF) and Pollution Load Index (PLI)). Potential Ecological Risk Index (RI) was assessed by the toxicity and combined effects of heavy metals studied. Toxicological models provided by USEPA was used for vulnerability assessment on human health via dermal contact. The results showed that the variation in total mean concentrations of heavy metals in the sediment of Soku Creek follows the order: Fe>Mn>Zn>Cu>Ni>Co>Cr>V>Pb>Cd. Concentration of all the heavy metals detected were far above the permissible limits except for Cd (0.01 ± 0.003) mg/kg which concentration falls below the set limits of 0.04mg/kg. Based on the values obtained for Igeo, the sediments samples showed no contamination for Mn, Zn, Cu, Cr in all the Sediments, extremely contaminated with Pb in SES 3 and SES4, Fe in all sediments (SES1-SES5)., Moderately to strongly contaminated for Ni in SES1, V in SES1 and SES3. Co-in SES1, SES2 and SES5. Enrichment factor showed no enrichment to minor enrichment for Ni, Mn, Fe, Cd, Zn, Cu, Cr, V and Co. Moderate enrichment for Pb was recorded in SES3 and SES4. Contamination factor showed low degree of contamination in all the sediments to considerable degree of contamination of Pb in SES 3 and SES4. PLI indicated no pollution for heavy metal in all the sediment sample. The ecological risk indicated low ecological risk for all the heavy metals under investigation. Human health risk indicated that hazard index (HI)values for the heavy metals were<1in all stations and no potential noncarcinogenic risk for adults. The excess carcinogenic risk (ECR) is 0.017 times higher than the USEPA acceptable range in SES1. From the study it can be concluded that there was progressive deterioration of the sediment quality with a potential negative effect. Periodic and regular monitoring becomes necessary to avert changes in the qualities of the sediments of the area and impending dangers on human health, and other benthic organisms.

Keywords: sediment quality, geo-accumulation, heavy metals, enrichment factor, soku creek, health risk, vulnerability, ecological risk

Introduction

Multiple application of metals in the industrial, domestic, agricultural, medical and technology have led to their distribution and availability in the environment raising concerns on potential hazards on human health and the environment at large (Mishra *et al*., 2019; Mathur*et al*., 2022) [18].

The aquatic environment is one component of the environment that had suffered from a great deal of heavy metal pollution serving as a sink for varying degrees and class of heavy metal from different sources (Jain *et al*., 2008; Ideriah*et al*., 2012; Guan *et al*., 2018) [13, 10, 12]. These metals occur in very low amounts ranging from micrograms to nano grams pe liter (Ying *et al*., 2002) [35] and are distributed among the different compartments within the environment (Xu *et al*., 2014) [34]. Sediments in estuarine/coastal ecosystems are major sinks for heavy metals (Chapman *et al*., 1998) allowing these metals in food chain and web (Pan and Wang, 2012) [25] significantly threatening human health upon exposure and changes in environmental condition (Tian *et al*., 2020) [26].

Sediment pollution has become a source of concern to all major stakeholders. In recent times, increased activities of oil bunkering (kpoo fire) and the practice of dumping domestic wastes by the river/creek side has further worsened the contamination load and geochemical balance of heavy metals in the area (Moslenand Aigberua, 2018) [19]. Increased heavy metals in sediments haveconstantly resultedto a change in the qualities of the naturally alignedecological status (Ideriah *et al*., 2012; Paland Maiti, 2018; Wang *et al*., 2021) [12, 24, 30]. Contaminated water bodies cannot support human use and its constituent biotic communities which include fishes and other benthic organisms (Valavanidis *et al*., 2010; Ezenwa *et al*., 2022) [29, 8]. The impact on the food chains and food webs which represents the relationship and interdependence of one organism on another for food becomes impacted negatively. Humanswho feed at the highest level are faced with serious health hazards owing to increased concentrations (Alnabl*et al*., 2022). Disturbance on food chains can culminate into food insecurity, malnutrition, hunger andother impeding dangers (Nweke *et al*., 2018) [21] confronting coastal population (Zerizghi *et al*., 2022) [37]. Evaluating the ecological and health risks under heavy metal exposure are of great importance to the sustainability of the aquatic ecosysytem, biogeochemical cycles (Zaynab *et al*., 2022) [36].

Description of the study site and sampling techniques

Soku is located in Akukutoru Local Govertment Area of Rivers State, Nigeria. The community is host to three (3) flow stations (Ekulama I and II, and Soku Oil Ream Development Project (ORD) (Moslen and Aigberua, 2018) [19]. The oil field and the gas plant are surrounded by tidal estuarine water bodies from the Sombrero and Saint Bartholomew estuaries. The Soku oil field and gas plant are the major oil field facilities that deliver bulk of the gas to NLNG (The Nigeria Liquefied Natural Gas) situated at Finima, town in Bonny kingdom for exportation and also host to severalother small and medium oil and gas industries operating in different settlements separated by creeks within the area (Onuoha, 2016) [23]. From the inception of crude oil activities till date, the area has suffered from long term impacts of crudeoil spillsand other hazardous substances emanating from industrial wastes and effluents, raw materials, chemicals, and refined petroleum products, untreated sewage from humans, dredging activities, out board engine repairs. (Akujuru, 2016) [2]. Oil Spills occur accidentally and through the deliberate activities of the local populace who engage in illegal/artisanal refining popularly called bunkering or kpoo fire (Moslen and Aigberua, 2018) [19].

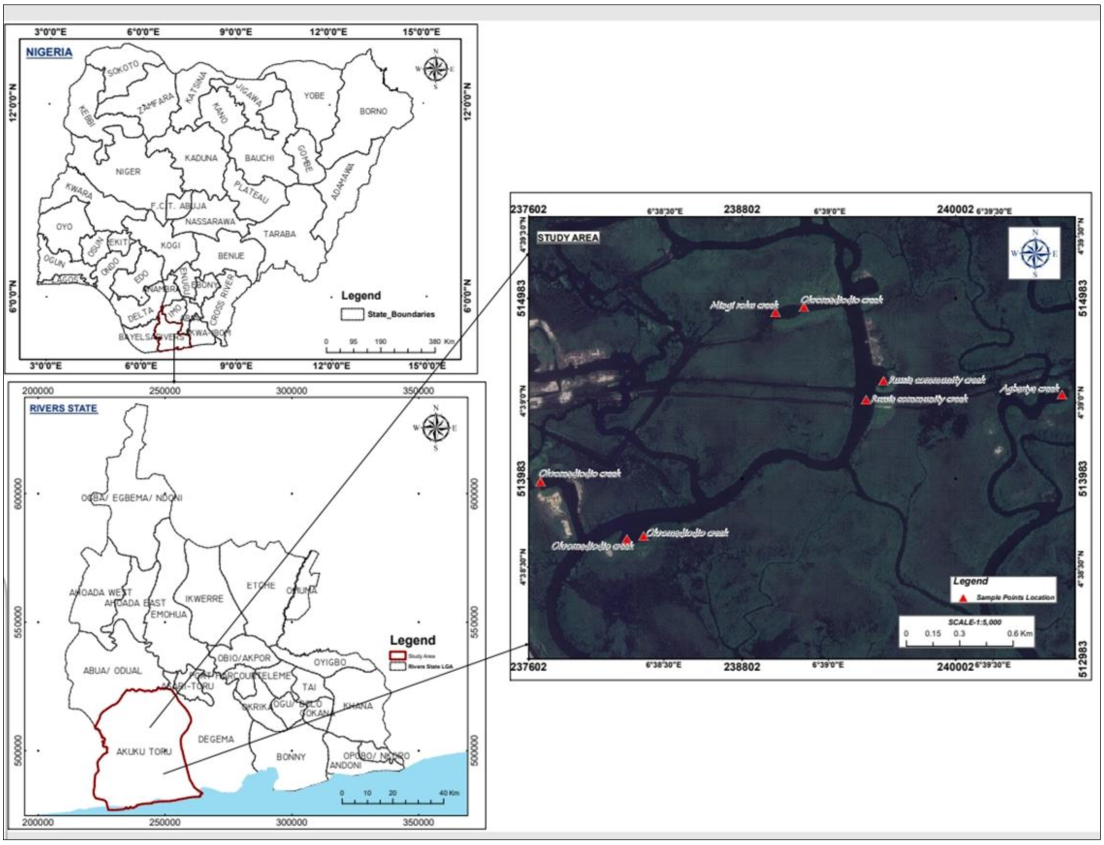

Fig 1: Map of the Study Area

Sample collection

Sediment samples were collected from five (5) different sampling stations labeled as (SES) from Soku Creek. The global positioning system (GPS) was used to record the geographical locations. Samples were also taken from sites other than the study site 10km away from the study site to represent background metal concentration. Sediments samples were collected by the grab method using the Eckman grab.

Table 1: Ecological Setting of Study Area

Station Number	Station Code	GPS Location	Station
1	SES1	N4º39" 1.46 E 639" 42.56	Agbariya Creek
2	SES2	4º38" 45.40 E6 º38"7.59	Mingi roku creek
3	SES3	N4º38" 35.09 E6 º38"23.37	Okromadiodio ICreek
4	SES4	N 4 º38" 35.62 E 6 º38"26.43	Okromadiodio Creek II
5	SES5	N4 º39" 0.39 E6º39" 10.04	Russia Community Creek

Determination of heavy metal level in study site

The sediment sample (5g) was weighed and transferred into100ml glass beakers. 2ml concentrated nitric acid, 10ml concentrated hydrochloric acid, and 20ml distilled water was added to each sample for digestion on a hot plate (Corning PC-351 model) and was left to cool at room temperature. Furthermore, filtered and transferred quantitatively into volumetric flask. 50ml distilled water was added after which samples were transferred into sample bottles for Atomic Absorption Spectrophotometer (AAS), GBC, 908PBMT model. Calibrations made with known standard concentrations and concentration of heavy metals under study was evaluated from the data generated using the calibration curve was applicable (Aiberua *et al*., 2020).

Determination of indices for sediment quality

Four (4) different types of indices and classification were employed. Geo-accumulation Index (Igeo), Enrichment Factor (EF), Contamination Factor (CF) and Pollution Load Index (PLI) were used for the assessment of sediment quality (Müller, 1969).

Equation (1) was used for the calculation for (I-geo)

$$\text{I-geo} = Log\ 2\frac{Cx}{1.5*Cbn} \quad (1)$$

Where Cx = Heavy metal concentration in sample environment, Cbn = Geochemical background value, 1.5=constant compensating for weathering and lithogenic effects. Classification for this index is given in the following order: I-geo < 0 = practically unpolluted, 0 < I-geo < 1 = unpolluted to moderated polluted,1 < I-geo < 2 = moderately polluted,2 < I-geo < 3 = moderately to heavily polluted, 3 < I-geo < 4 = Heavily polluted,4 < I-geo < 5 = Heavily to extremely polluted, I-geo > 5= extremely polluted (Krampha*et al*., 2019).

Equation (2) was use for calculation of the Enrichment factor (EF) using the conservative elements as Fe.

$$EF = {(Cx/Fe)sample}\Big/{(Cx/Fe)background} \quad (2)$$

Where Cx and Cx background = concentration of heavy metals in the sediment. (Cx /Fe) background =background values of Fe. Indicative of different levels of pollution is of the order: (i) 0–1 = background concentration or no enrichment; (ii) 1–3 = minor, (iii) 3–5 = moderate, (iv) 5–10 = moderately severe, (v) 10- 25 = severe, (vi) 25–50 = very severe, and (vi) >50= extremely severe (Janadeleh *et al*., 2018).

Using Equations (3) and (4), the Contamination Factor (CF) and Pollution Load Index (PLI) were evaluated (Tomlinson *et al*., 1980)

$$PLI = \sqrt[n]{CF1x\ CF2\ x\ CF3\ x\ CFn} \quad (3)$$

$$CF = {Cx}/{Cbn} \quad (4)$$

Where CF= is the contamination factor, (Cx)= concentration of heavy metal in sample, Cbn= background value, n= number of heavy metals under study, PLI = pollution load index. Established classification values are as follows PLI = 0 indicate the absence of heavy metal contamination, PLI =1 base line due to background value PLI >1 shows the presence of heavy metal pollution and progressive deterioration.

Ecological risk assessment

Potential Ecological Risk Index (RI) by Hakänson (1980) was used and calculated according to equations (5), (6) and (7)

Fi= $Cn\ /Cr$ …………. (5)

E i r= Ti r x Fi ...………. (6)

RI = ∑ni=1 E i r ……..….. (7)

Where Fi= single metal pollution index; Cn= concentration of metal in the samples; Cbn= background value for the metal; E i r = monomial potential ecological risk factor; Ti r = metal toxic response factor

Ti r for Ni= 5, Mn=1, Pb=5, Cd= 30, Zn=1, Cu= 5, Cr= 2, V=2, Co=5. Ecological risk given in order established: Eir 40 = low risk, 40<Eir 80 = moderate risk, 80, Eir ¸180= considerable risk, 180< Eir320 = high risk, Eir 320= Very High risk. (RI) follows the order: RI<110 = low risk, 110< RI<200= moderate risk, 200<RI<400= considerable risk, RI>400 very High Risk

Human health vulnerability assessment

The health risk assessment cancer and non-cancer risk of heavy metals in this study was achieved by human models' parameters in accordance with (USEPA, 2010). Exposure to toxic heavy metals was evaluated using equation (8) via dermal contact.

$$Dermal_{\ Exposure} = {C \times CF \times SA \times AF \times ABS \times EF \times ED}\big/{BW \times AT} \quad (8)$$

Where C = concentration of heavy metals in the sediment, conversion factor (CF)=(10−6 kg/mg); EF= exposure frequency (350 days/year); ED =exposure duration (30 years); BW= body weight (70 kg); SA= skin surface area exposed (5700 cm2); AF = sediment to skin adherence factor (0.07 mg/cm2); ABS=sediment dermal absorption (0.001), AT= period of effects: (For non-cancer effects, AT= ED × 365 days; cancer effects, AT= 70 × 365 = 25,550 days).

The non-cancer risk of heavy metal concentrations in sediment was evaluated by the use of Hazard Quotient (HQ) and Hazard Index (HI). Equations (9) and (10) was employed for the calculation and characterization

HQ= Dermal Exposure /RfD ----------- (9)

HI=HQ1+HQ2 +HQ3 +⋯HQn ----------- (10)

Where HQ = hazard quotient; RFD = Reference dose via dermal contact (mg/kg/day), n= total number of heavy metals under investigation; Dermal RFD (mg/kg/day) for the metals under study are given as follows: Ni= 0.0008, Mn= 0.00184, Fe= 45 Pb= 0.000525, Cd= 0.42, Zn= 0.012, Cu= 0.0054, Cr=0.003, V= 0.01, Co= 0.0000057

In the characterization, HI < 1.0, it is an indication that significant toxic interactions of heavy metals would not occur. HI >1.0, there may be a concern for vulnerability and potential non-cancer health effects.

Cancer risk was estimated as the posibility of developing cancer upon exposure to carcinogenic metals and estimated using equation (11)

Cancer Risk=∑CR = Dermal Exposure ×CSF----------- (11)

The slope factor converts estimated daily intakes and exposure directly to the incremental risk of an individual developing cancer. Equation (10) wasused to calculate the cancer risk

Where CSF=cancer slope factor. Slope factor converts estimated daily intake of metals over a lifetime of exposure directly to the incremental risk of an individual developing cancer for the metals under study is given as: (Ni= 42.5, Pb= 0.00085, Cd= 0.38) (mg/kg/day).

Statistical analysis
The data were statistically analyzed by SPSS software version 26 and were expressed as Mean ± Standard Deviation (SD).

Results and discussion
Variation in total mean concentrations of metals from Soku Creek alongside values from some regulatory body is presented Table 1. The computed average rank of metals follows: Fe> Mn> Zn> Cu> Ni> Co> Cr> V> Pb> Cd and concentration of heavy metals detected, all far above the permissible limits of (WHO, 2008 and FEPA, 1991) [33, 9], except for Cd (0.01 ± 0.003) mg/kg which concentration falls below the set limits of 0.04mg/kg, Table 1. Heavy metals beyond the detection limit of the instrument are Pb (SES1, SES2, SES5), Cd (SES3, SES5), Ni, Cu, Cr, V and Co in SES5 Figure 1. The result obtained for contamination load and ecological risk is presented in Tables 2-5. Values obtained are compared to the values in contamination and pollution classification and risk ranging from uncontaminated to heavily contaminated sample site from the study. The background values used were reference values of heavy metals from (WHO, 2008 and FEPA 1991) [9]. Based on the values gotten, Igeo, the sediments samples showed no contamination for Mn, Zn, Cu, Cr in all the Sediments. However, extremely contaminated with Pb in SES 3 and SES4, Fe in all sediments (SES1-5)., Moderately to strongly contaminated for Ni in SES1, V in SES1 and SES3. Co in SES 1, SES 2 and SES 5. Enrichment factor showed no enrichment to minor enrichment for Ni, Mn, Fe, Cd, Zn, Cu, Cr, V and Co. Moderate enrichment for Pb was recorded in SES3 and SES4 showed low degree of contamination in all the sediments to considerable degree of contamination of Pb in SES 3 and 4. PLI recorded no pollution for selected heavy metal in this study. The values obtained were equal to zero. The result obtained for the ecological risk indicated low ecological risk for all the heavy metals under investigation.

Table 1: Total Heavy Metal Concentration in Sediment of Soku Creek

S/No.	Heavy metal	Conc.(mg/kg)	Maximum Permissible Limits
1	Ni	1.83 ± 0.40	0.07 (FEPA, 1991)
2	Mn	74.42 ± 9.43	30 (WHO,2004)
3	Fe	3040.45 ± 280.97	50 (WHO, 2008)
4	Pb	0.71 ± 0.23	0.01 (WHO,2008)
5	Cd	0.10 ± 0.03	0.04 (WHO,2008)
6	Zn	12.86 ± 0.68	5 (WHO1997)
7	Cu	2.04 ± 0.37	2 (WHO, 2008)
8	Cr	1.35 ± 0.30	0.5 (WHO, 2008)
9	V	0.90 ± 0.02	0.01 (FEPA, 1991)
10	Co	1.66 ±0.35	0.05 (FEPA,1991)

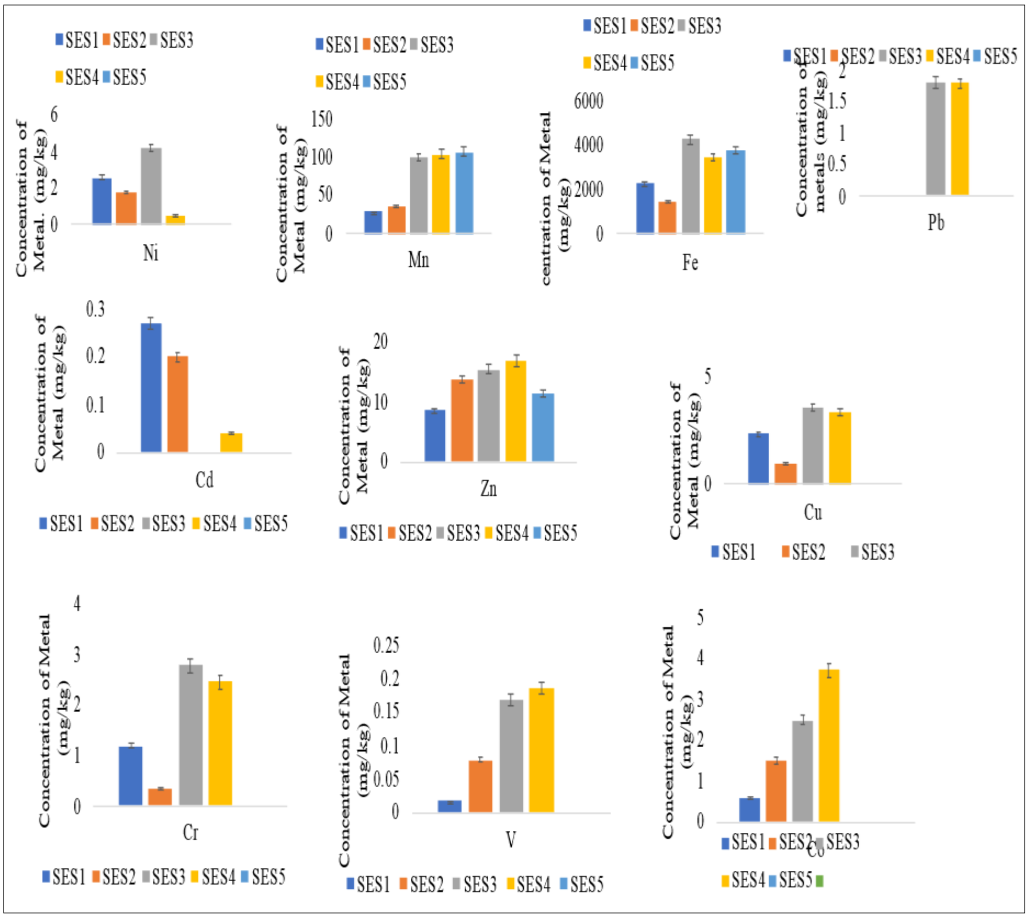

Fig 1: Heavy Metal Concentration in Sediments of Soku Creek

Table 2: Geo- Accumulation Index of Sediments from Soku Creek

Heavy Metal	SES1	SES2	SES3	SES4	SES5
Ni	4.61	4.10	5.33	2.33	ND
Mn	-0.70	-0.33	1.20	1.21	1.26
Fe	5.00	4.29	5.84	5.52	5.65
Pb	ND	ND	6.91	6.90	ND
Cd	2.20	1.74	ND	-0.60	ND
Zn	0.17	0.83	1.02	1.16	1.0
Cu	-0.4	-1.63	0.25	0.14	ND
Cr	1.00	-1.10	2.00	1.71	ND
V	0.10	2.40	3.50	3.63	ND
Co	3.00	4.31	5.05	5.63	ND

Table 3: Enrichment Factor of Sediments from Soku Creek

Heavy Metal	SES1	SES2	SES3	SES4	SES5
Ni	0.82	0.57	1.35	0.17	ND
Mn	0.02	0.03	0.08	0.08	0.08
Fe	1.00	0.65	2.00	1.54	1.67
Pb	ND	ND	4.00	4.0	ND
Cd	0.15	0.11	ND	0.02	ND
Zn	0.04	0.06	0.07	0.08	0.05
Cu	0.03	0.01	0.04	0.04	ND
Cr	0.05	0.02	0.12	0.11	ND
V	0.04	0.17	0.38	0.45	ND
Co	0.27	0.70	1.11	1.65	ND

Table 4: Computed Values for the Contamination Factor for Sediments from Soku Creek

Heavy Metal	SES1	SES2	SES3	SES4	SES5
Ni	0.82	0.57	1.4	0.17	ND
Mn	0.02	0.03	0.07	0.07	0.08
Fe	1.00	0.65	1.90	1.54	1.67
Pb	ND	ND	4.00	4.00	ND
Cd	0.15	0.11	ND	0.02	ND
Zn	0.04	0.06	0.07	0.07	0.05
Cu	0.03	0.01	0.04	0.04	ND
Cr	0.06	0.02	0.12	0.11	ND
V	0.04	0.17	0.38	0.41	ND
Co	0.27	0.66	1.11	1.65	ND
Sum	2.41	2.28	9.05	8.05	1.80

Table 5: Ecological Risk of Heavy Metal in Sediments from Soku Creek

Heavy Metal	SES1	SES2	SES3	SES4	SES5
Ni	4.09	2.86	6.72	0.84	ND
Mn	0.02	0.02	0.07	0.07	0.08
Fe	ND	ND	ND	ND	ND
Pb	ND	ND	20.03	19.81	ND
Cd	4.50	3.33	ND	0.66	ND
Zn	0.18	0.30	0.34	0.37	0.25
Cu	0.13	0.05	0.19	0.18	ND
Cr	0.10	0.03	0.24	0.21	ND
V	0.07	0.35	0.75	0.82	ND
Co	1.33	3.31	5.54	8.23	ND
PERI	10.45	10.28	33.92	31.24	0.33

Human health risk assessment of heavy metal from sediments from soku creek

The HI values were 0.006, 0,020, 0.0300, 0.939, 0.0003 for SES1, SES2, SES3, SES4 and SES5. The result indicated no potential noncarcinogenic risk for adults through the dermal contact. Excess carcinogenic risk (ECR) 0.017 times higher than the USEPA acceptable range in SES1, Tables 5 and 6.

Table 6: Target Hazard Evaluation of Heavy Metal from Sediments of Soku Creek

Heavy metal	SES1	SES2	SES3	SES4	SES5
Ni	1.45E-08	1.03E-08	2.41E-08	2.85E-09	ND
Mn	1.60E-07	2.05E-07	5.71E-07	5.94E-07	6.14E-07
Fe	5.7E-09	8.33E-06	2.44E-05	1.97E-05	2.14E-05
Pb	ND	ND	1.03E-08	1.01E-08	ND
Cd	1.54E-09	1.14E-09	ND	2.28E-10	ND
Zn	4.82E-08	7.73E-08	8.70E-08	9.56E-08	6.46E-08
Cu	1.4E-08	5.52E-09	2.03E-08	1.92E-08	ND
Cr	6.78E-09	2.00E-09	1.58E-08	1.40E-08	ND
V	9.12E-11	4.45E-10	9.63E-10	1.06E-09	ND
Co	3.42E-09	8.5E-09	1.42E-08	2.11E-08	ND
HI	0.0061	0.020	0.0300	0.0939	0.0003

Table 7: Cancer Risk Evaluation of Heavy Metal from Sediments of Soku Creek

Heavy Metal	SES1	SES2	SES3	SE4	SES5
Ni	5.71E-09	2.51E-17	2.6E-25	3.17E-34	ND
Pb	9.90E-09	4.83E-18	ND	ND	ND
Cd	1.22E-09	1.04E-18	7.06E-27	4.23E-35	ND
ECR	1.70E-08	3.10E-17	2.67E-25	3.59E-34	ND

The heavy metals are continuously lodged in the marine sediment as receptacle (Chen *et al*., 2021). These metals pose toxicity, bioaccumulation, and biomagnification affecting the ecosystem, human health, and other living organisms (Ali and Khan, 2019) [3]. In recent years, vulnerability due to heavy metal deposition in river sediments has become a major public-health concerns for researchers. Several similar studies have on aquatic sediments have been revealed to be highly loaded and polluted with heavy metals heavy metals (Janadeleh *et al*., 2018; Ngwoke *et al*.,2019; Ogundele and Ayeku, 2020) [19, 22]. The evaluation of sediment contamination status was achieved by the several potential ecological risk index (PERI) as well human health risk assessment (Jimoh *et al*., 2020) [15]. Contamination status showed extremely contamination for Pb in sediment sample 3 and 4 and moderate contamination for Ni in sediment sample 1. In all samples heavy pollution indicated zero and low ecological risk. Human health vulnerability assessment of heavy metal via dermal contact was evaluated by determining the target hazard index (HI) and cancer effects over a period of time. The HI value indicated no potential hazards for adults. Carcinogenic risk using excess cancer risk (ECR) indicated the excess cancer risk was 0.017 times higher than the USEPA acceptable range in SES1. Under the control and monitoring conditions, ECR of 1×10^{-6} and 1×10^{-4} represents an acceptable risk level. Other the hand, if ECR is a>1 × 10-4 then there is cancer risk upon contact. From the study, the excess cancer risk was 0.017 times higher than the USEPA acceptable range is an indication of cancer risk of heavy metal in sediment sample from the study site.

Conclusion

The results from the study established gradual deterioration of the sediment quality with a potential negative effect. Periodic and regular monitoring is necessary to avert changes in the qualities of the naturally aligned ecological status of the area and impending dangers on human health and other benthic organisms.

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