



Sediment Quality of Orashi River at Four Oil Producing Communities of Nigeria

AKACHUKWU, D; *NNAJI, JC; OJIMELUKWE, P., ONOJA, S; ODO, S

Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria
*Corresponding Author Email: nnaji.jude@mouau.edu.ng

ABSTRACT: Bed Sediment samples were collected in the Dry Season from Orashi River at three sampling sites each located in Mmahu, Opuoma, Abacheke and Ogwu Aniocha communities. Physicochemical parameters, hydrocarbon and heavy metal (As, Cd, Fe and Pb) concentrations were determined with standard methods. Results showed that total petroleum hydrocarbon (TPH) ranged from 0.11 ± 0.03 to 1.91 ± 0.25 mg/kg while total hydrocarbon content (THC) and oil and grease had ranges of 0.28 ± 0.06 - 2.98 ± 0.19 and 0.69 ± 0.09 - 3.60 ± 0.57 mg/kg respectively. The sediment samples were classified as unpolluted in terms of TPH. Mean values for pH had a range of 4.33 ± 0.22 - 6.60 ± 0.52 while the texture of most samples was sandy. Mean organic carbon contents ranged from 0.58 ± 0.07 to 3.15 ± 0.66 % and mean total nitrogen and total phosphorus had ranges of 0.30 ± 0.00 - 2.77 ± 0.46 and 17.34 ± 1.65 - 29.48 ± 1.63 mg/kg respectively. Mean Mg concentrations were significantly higher ($P < 0.05$) than the concentrations of other exchangeable bases and mean As concentration had a range of 1.175 ± 0.086 - 1.291 ± 0.335 mg/kg. Mean Cd concentrations ranged from 0.948 ± 0.072 to 3.120 ± 0.131 mg/kg while mean Fe and Pb concentrations had ranges of 57.324 ± 10.530 - 159.707 ± 41.192 and 1.300 ± 0.295 - 7.462 ± 0.861 mg/kg respectively. As and Pb values were lower than the sediment quality guidelines (SQG) but Cd values were higher than the guidelines in all sites. Contamination factors (CFs) for As and Pb indicated low contamination while CFs for Cd indicated moderate to considerable contamination. Geo-accumulation index (Igeo) values for As and Pb at all sites and that of Cd at one site indicated unpolluted, Igeo values for Cd at all other sites ranged between 0.210 and 1.571 indicating unpolluted to moderately polluted status.

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Anthropogenic activities like oil and gas production results in the production of pollutants like petroleum hydrocarbons and trace metals which contaminate environmental matrices. Studies have revealed that subtle changes which occur in aquatic and terrestrial ecosystems of the Niger Delta correlate with petroleum activities and it affects human health, ecosystems, cultural and historical resources (Ogbeibu *et al.*, 2018; Nwachukwu and Osuagwu, 2014). Oil and gas companies like Shell Petroleum Development Company (SPDC), Nigerian Agip Oil Company (NAOC) and Nigeria Petroleum Development Company (NPDC) operate in Ohaji-Egbema Local Government Area (LGA) of Imo State. Their operations results in oil spill incidences and gas flaring which can potentially pollute the environment (Rainforest News, 2010; Daily Post, 2015). Oil companies like Orient Petroleum, Oil Indian and Sterling Oil E&P Production Co. Ltd (SEPCO) also operate in Ogwu Aniocha, Ogwu Ikpele and Usham, all in Ogbaru LGA of Anambra State (Sun News 2019; Business and Maritime West Africa, 2019). On entry into waterbodies, pollutants are partitioned between water, sediments, suspended solids and aquatic biota

and they tend to accumulate more in sediments than in water and aquatic organisms (Kumar *et al.*, 2010; Umesi *et al.*, 2013). Study of bed sediments of a waterbody is important since it serves as a sink for metals and other materials which are also remobilized from sediments into the overlying water column depending on pH and other conditions. Bottom sediment analysis give an idea of the history of contamination and the types of contaminants present in water (Araujo *et al.*, 1988; Zvinowanda *et al.*, 2009). In addition, the overlying water is in dynamic equilibrium with sediment and the quality of sediment influences the biological productivity of waterbodies (Gupte and Shaikh, 2014). Due to the paucity of data, the aim of this study was to determine the quality of sediments collected from sites on Orashi River located at Mmahu, Opuoma, Abacheke and Ogwu Aniocha communities.

MATERIALS AND METHODS

Description of Study Areas: Orashi or Ulasi River is located in the lower Niger River basin and it is a tributary of Oguta Lake flowing through Anambra,

Imo, Bayelsa and Rivers States, Nigeria. The source of Orashi River is the rocks of Ezeama community of Dikenafai, Imo State which is 183 m above mean sea level. From Dikenafai, it flows through communities like Urualla, Ozubulu, Oguta, Opuoma, Mmahu, Abacheke, Omoku and Epie before emptying into the Atlantic Ocean (Alchetron, 2018). Opuoma, Mmahu and Abacheke are in Ohaji-Egbema Local Government Area (LGA) of Imo State. At Ozubulu, Orashi takes a left turn and flows through Okija but a westerly course flows through communities like Ogwu-Aniocha and Ogwu-Ikpele in Ogbaru LGA in Anambra State. Orashi R. splits into two at Egbema in Rivers State with the larger right portion flowing through Eluku before splitting again into two and emptying into the Gulf of Biafra. The Orashi Region is home to over 35% of the oil wells in the Niger Delta States of Imo and Rivers.

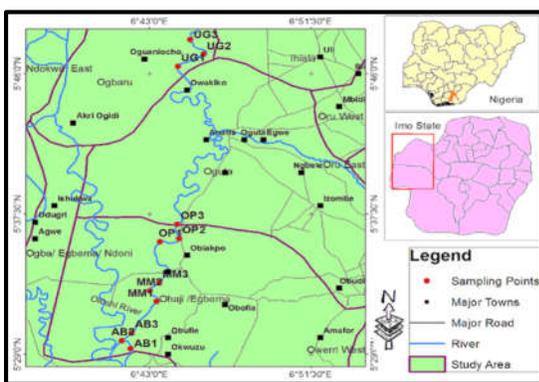


Fig. 1. Sampling Points

Table 1. GPS Coordinates of the Sampling Points

LOCATION	SAMPLE ID	COORDINATES	
		Easting	Northing
Abacheke 1	AB1	006 42".272	05 30".779
Abacheke 2	AB2	006 42".379	05 30".795
Abacheke 3	AB3	006 42".688	05 30".015
Mmahu 1	MM1	006 43".843	05 33".815
Mmahu 2	MM2	006 43".878	05 33".923
Mmahu 3	MM3	006 43".908	05 33".966
Opuoma 1	OP1	006 44".511	05 36".273
Opuoma 2	OP2	006 44".565	05 36".205
Opuoma 3	OP3	006 44".586	05 36".058
Ogwu-Aniocha 1	UG1	006 44".146	05 47".156
Ogwu-Aniocha 2	UG2	006 45".095	05 47".759
Ogwu-Aniocha 3	UG3	006 45".224	05 48".172

Sampling: Triplicate bed sediment samples were collected in the Dry Season with Eckman Grab sampler from 12 sampling sites (Fig. 1) in Mmahu, Opuoma, Abacheke (Ohaji/Egbema LGA) and Ogwu Aniocha (Ogbaru LGA) at three different sites at each location: down-stream (point 1), mid-stream (point 2) and upstream (point 3). The samples were wrapped with polythene bags, kept in an ice chest followed by transportation to the laboratory for analysis. Coordinates of the study sites (Table 1) were measured

with GRAMIN global positioning system (GPS) instrument.

Sample Pre-treatment: Extraneous materials were removed from sediment samples. All samples for organic carbon and heavy metal analyses were oven dried at 110 °C while those for other analyses were air dried. Dry sediment samples from each treatment were ground into fine powder with acid washed plastic mortar and pestle. Samples from each treatment were divided into two and passed separately, through 2 mm and 0.2 mm sieves. They were then stored in dry acid washed polyethylene bottles with screw caps, at room temperature, prior to analyses. The 2 mm samples were used for the determination of pH, total phosphorus, total nitrogen, particle size and exchangeable bases while the 0.2 mm samples were used for organic carbon, organic matter and metal analyses.

Determination of Physicochemical Parameters: The pH of the dry sediments was determined by inserting a pre-calibrated digital pH meter into a 1:2.5 sediment-distilled water slurry and taking the reading. Organic carbon was determined by the wet-acid oxidation method (Walkey and Black, 1934). Organic Matter was analysed by ignition of the sample in a muffle furnace at 500 °C for 4 h and subsequently cooling in a desiccator to achieve constant weight (Elith and Garwood, 2001). Total nitrogen (TN) was analyzed using the Kjeldahl method while total Phosphorus was analysed in each sample by digestion with perchloric acid, dilution of digest with distilled-deionised water, filtration of the resulting solution and utilization of the stannous chloride method to determine P in mg/kg (Agbenin, 1995; APHA, 2012). Particle size analysis was done using the hydrometer method which utilizes 50 % Calgon (sodium hexametaphosphate) as dispersing agent (Bouyocous, 1951). Total exchangeable bases (K, Na, Ca and Mg) were determined by the ammonium acetate (NH₄AOC) extraction method (Jackson, 1958). Sample (10 g) was extracted with 100 ml of solvent mix (1:1 Hexane: Dichloromethane) in a soxhlet extractor and concentrated to 2 ml. The extract was passed through a packed and conditioned column containing glass wool, baked silica gel and anhydrous sodium sulphate at 105 °C with solvent to clean up the extract. 1 µL of the extract was injected into and analysed for total petroleum hydrocarbons (TPH) with Agilent 7890A Gas Chromatography system with flame Ionization detector (GC-FID). Sample (10 g) was weighed into a soxhlet extractor thimble and 100 mL of tetrachloroethylene was added, refluxed three times before being concentrated with rotary evaporator. The extract was cleaned up with sodium sulphate

anhydrous and glass wool. The cuvette of InfraCal 2 oil in water/soil Analyzer (Infra-Red spectrophotometer) was filled with the extract and oil and grease content (O&G) was read after blanking with the extracting solvent. For total hydrocarbon content (THC), the extract was cleaned up with 100-200 mm mesh silica gel and anhydrous sodium sulphate before being analysed with InfraCal 2 analyzer. All analyses were done in triplicate.

Heavy Metal Analysis: Serial Dilution and Preparation of Calibration Curves: Stock solutions (1000 ppm) of the metal (Fe, Pb, Cd and As) were prepared with the appropriate salts [Cd (NO₃)₂.4H₂O, Pb (NO₃)₂, As₂O₃ and Fe (NO₃)₃] of each metal. Five standard solutions of each metal were prepared from appropriate stock solution by serial dilution. The standards solutions were aspirated into a Flame Atomic Absorption Spectrophotometer (SpectrAA 100) and the absorbances obtained for the standard solutions of a particular metal were used in drawing calibration curves.

Digestion of Samples: Sample (5 g) of the sieved sediment sample was weighed with electronic weighing balance into a 100 ml beaker and digested with 20 ml mixed acids (1 perchloric acid:3 concentrated nitric acid). Anti-bump and 5 ml of distilled/de-ionized water were added and the crucible was heated gently with a hotplate in a fume cupboard to partial dryness. The beaker was then allowed to cool and 10 ml of distilled-deionized water was added. This was stirred gently with glass rod and filtered through Whatman No. 42 filter paper into a 50 ml volumetric flask and made up to mark with distilled-deionized water

Method validation, Metal Analysis and Conversion of results: The procedure and method was validated by the use of a standard reference sample. This involved determining the metal concentrations in a standard reference food sample from International Atomic Energy Agency (IAEA) obtained through BGL Laboratories, Port-Harcourt. The standard reference material was digested and analyzed in triplicate with the methods used for the samples. The percentage recovery was calculated and the digested samples and blank solutions were aspirated in triplicate into the AAS instrument and the absorbance recorded. As was analyzed with the hydride generation accessory with closed end cell. Metal concentrations for the samples obtained from extrapolation on the calibration curves were in weight/volume basis (mg/L) and they were converted to weight/weight basis (mg/kg) using the formula:

$$\text{Conc.} \left(\frac{\text{mg}}{\text{kg}} \right) = \frac{(\text{conc.} \frac{\text{mg}}{\text{L}} \times \text{dilution factor})}{\text{wt of sample digested (g)}} \quad 1$$

Dilution factor = 50 = volume in ml of the digest solution

Calculation of Metal Contamination Indices

The indices calculated in this study were:

(a) Contamination factor (CF). This is expressed as;

$$CF = \frac{C_{\text{heavy metal}}}{C_{\text{Target ref value}}} \quad 2$$

Where $C_{\text{heavy metal}}$ is the concentration of a metal in the sample and $C_{\text{Target ref value}}$ is the background/recommended value for the metal in sediments.

(b) Pollution load index (PLI). PLI is expressed as (Tomilson *et al.*, 1980);

$$PLI = (CF1 \times CF2 \times CF3 \dots \dots \times CFn)^{\frac{1}{n}} \quad 3$$

Where CFn is the CF value of metal, n.

(c) Geoaccumulation index (Igeo). The Igeo of the metals was calculated using the equation of Christophoridis *et al.* (2009):

$$I_{\text{geo}} = \text{Log}_2 \left(\frac{C_n}{1.5B_n} \right) \quad 4$$

(C_n = measured concentration of metal in sediment, B_n = geochemical background criteria for sediment, 1.5 is a constant which allows for fluctuations of a given metal in the environment in addition to small anthropogenic influences.

RESULTS AND DISCUSSION

Table 2 shows the mean total petroleum hydrocarbon (TPH), total hydrocarbon content (THC) and oil and grease (O&G) concentrations in the sediment samples. TPH ranged from 0.11 ±0.03 at Opuoma site 2 (OP2) to 1.91 ±0.25 mg/kg at Ogwu Aniocha site 3 (OG3) while THC and O&G had ranges of 0.28 ±0.06-2.98 ±0.19 and 0.69 ±0.09-3.60 ±0.57 mg/kg respectively. Significantly higher values (P<0.05) for the three parameters were obtained in the three samples from Ogwu Aniocha compared to the samples from Mmahu, Opuoma and Abacheke. There are no national or international sediment quality guidelines for TPH, THC or O&G but Massoud *et al.* (1996) and Ritchie *et al.* (2001) suggested four levels of pollution with respect to TPH pollution namely; unpolluted (10-15 mg/kg), slightly polluted (15-50 mg/kg), moderately

polluted (50-200 mg/kg) and heavily polluted (>200 mg/kg).

Table 2. Mean (\pm SD) TPH, THC and Oil & Grease Contents of Sediment Samples

Sample ID	TPH (mg/kg)	THC (mg/kg)	Oil & Grease (mg/kg)
MM1	0.25 \pm 0.11 ^a	0.56 \pm 0.07 ^a	0.72 \pm 0.15 ^a
MM2	0.31 \pm 0.09 ^a	0.87 \pm 0.22 ^b	1.30 \pm 0.24 ^b
MM3	0.19 \pm 0.05 ^b	0.59 \pm 0.09 ^a	0.81 \pm 0.16 ^a
OP1	0.15 \pm 0.01 ^b	0.32 \pm 0.11 ^c	0.42 \pm 0.05 ^c
OP2	0.11 \pm 0.03 ^b	0.28 \pm 0.06 ^c	0.45 \pm 0.12 ^c
OP3	0.20 \pm 0.07 ^b	0.52 \pm 0.16 ^a	1.33 \pm 0.14 ^b
AB1	0.24 \pm 0.04 ^a	0.53 \pm 0.09 ^a	0.69 \pm 0.09 ^a
AB2	0.28 \pm 0.08 ^a	0.61 \pm 0.13 ^a	1.07 \pm 0.06 ^b
AB3	0.17 \pm 0.02 ^b	0.46 \pm 0.08 ^a	0.65 \pm 0.02 ^a
OG1	0.94 \pm 0.40 ^c	2.06 \pm 0.42 ^d	2.68 \pm 0.33 ^d
OG2	1.53 \pm 0.38 ^c	2.55 \pm 0.37 ^d	3.11 \pm 0.61 ^c
OG3	1.91 \pm 0.25 ^d	2.98 \pm 0.19 ^c	3.60 \pm 0.57 ^c

MM = Mmahu, OP = Opuoma, AB = Abacheke, OG = Ogwu Aniocha; Values with the same superscript on the same column were similar ($P > 0.05$)

Based on this, the sediment samples collected from the 12 sampling sites in the four stations can be regarded as unpolluted in terms of TPH. Adeniji *et al.* (2017) in a study of Algoa Bay, South Africa observed that pH concentrations in the sediment samples ranged from 0.72 to 27.03 mg/kg (dry weight basis) while Inyang *et al.* (2018) obtained TPH concentration range of 270-830 mg/kg in the sediment samples of Qua-Iboe River, Akwa-Ibom State. These values were much higher than the TPH values obtained in this study. Seiyaboh *et al.* (2016) analyzed Orashi River sediment samples collected from five sampling stations within Rivers State and obtained a THC range of 4.96 - 9.62 mg/kg which is much higher than the range for this study. The mean physicochemical parameters of the sediment samples are shown in Table 3. Mean values for pH, with a range of 4.33 \pm 0.22 - 6.60 \pm 0.52, were mostly in the acidic region while particle size analysis indicated that the texture of most samples was sand. Verla *et al.* (2019) obtained a pH range of 6.81-7.55 in the sediments of Orashi River at its confluence with Oguta Lake in Oguta LGA of Imo State. Mean organic carbon content had a range of 0.58 \pm 0.07 - 3.15 \pm 0.66 % while mean organic matter content ranged from 0.65 \pm 0.02 to 4.64 \pm 0.73. Mean values for total nitrogen and total phosphorus had ranges of 0.30 \pm 0.00 - 2.77 \pm 0.46 and 17.34 \pm 1.65 - 29.48 \pm 1.63 mg/kg respectively. Seiyaboh *et al.* (2016) recorded a range of 2.51 - 4.01 mg/kg in dry season for total nitrogen for sediments of Orashi River which is higher than the values for this study. Exchangeable bases (K, Na, Ca and Mg) were present in all the samples from all the sites and had ranges of 0.04 \pm 0.00-0.15 \pm 0.03 for K, 0.21 \pm 0.03-0.36 \pm 0.02 for Na, 0.40 \pm 0.01-1.65 \pm 0.03 for Ca and 4.11 \pm 0.53-10.84 \pm 1.72 Cmol/kg for Mg. Mean Mg concentrations were significantly higher ($P < 0.05$) than the concentrations of other exchangeable bases in

all the samples. The heavy metal concentrations are shown in Table 4. As was detected in samples from only three sites with a range of 1.175 \pm 0.086-1.291 \pm 0.335 mg/kg. The soil quality guidelines (SQG) for As is 7.24 mg/kg and this was much higher than all the mean values recorded for all the samples. Mean Cd concentrations ranged from 0.948 \pm 0.072 to 3.120 \pm 0.131 mg/kg which were higher than the ISQG guideline value of 0.7 mg/kg. Ranges for mean Fe and Pb concentrations were 57.324 \pm 10.530-159.707 \pm 41.192 and 1.300 \pm 0.295-7.462 \pm 0.861 mg/kg respectively. Pb concentrations were much lower than the SGQ value of 30.2 mg/kg. Kpee and Ekpete (2014) in a study of sediment samples collected from Kalabari Creeks recorded mean values of 4,767.06 \pm 076.5 mg/kg for Fe and 1.63 \pm 1.16 mg/kg for Pb. Mean Fe values for this study were lower than these values but mean Pb values were similar to their values. Verla *et al.* (2019) obtained a range of 0.04-0.09 and 0.28-0.99 mg/kg for Fe and As concentrations respectively in the sediments of Orashi River at Oguta. These values were lower than the values for Fe and As in this study. Contamination factors (CF), geoaccumulation index (Igeo) and pollution load index (PLI) values are shown in Table 5. According to Hakanson (1980), range of values for CF are classified as follows: CF<1 indicates low contamination; 1<CF<3 indicates moderate contamination; 3<CF<6 indicates considerable contamination and CF>6 indicates very high contamination. CFs for As and Pb were all less than 1 at all the sites indicating low contamination. However, CFs for Cd were all greater than 1 with values at all sites in Ogwu Aniocha indicating considerable contamination while sites in Mmahu, Opuoma and Abacheke indicated moderate contamination except Abacheke site 2 with a value of 3.009 which also indicated considerable contamination. When PLI is greater than 1, the sediment is said to be polluted, PLI value equal to 1 signifies baseline level of pollution while PLI value less than 1 represents a non-polluted area. PLI values for all sites were all below 1 indicating that the sediments were not polluted with respect to the three heavy metals (As, Cd and Pb). Classes of geo-accumulation index are (Huu *et al.*, 2010); Igeo < 0 = unpolluted, 0-1 = unpolluted to moderately polluted, 1-2 = moderately polluted, 2-3 = moderately to strongly polluted, 3-4 = strongly polluted, 4-5 = strongly to extremely polluted and > 5 = extremely polluted. While the Igeo values for As and Pb at all sites and the Igeo values for Cd at the site MM2 were all below 0 indicating unpolluted, Igeo values for Cd at all other sites ranged between 0.210 and 1.571 indicating unpolluted to moderately polluted.

Table 3. Mean (\pm SD) Physicochemical Parameters of Sediment Samples

Sample ID	pH	Particle Size (%)			Texture	OC (%)	OM (%)	TN (mg/kg)	TP (mg/kg)	Exchangeable bases (Cmol/kg)			
		Sand	Silt	Clay						K	Na	Ca	Mg
MM1	4.81 $\pm 0.17^a$	88.54 $\pm 1.49^a$	8.12 $\pm 0.51^a$	3.34 $\pm 0.55^a$	Sand	0.83 $\pm 0.04^a$	1.43 $\pm 0.08^a$	0.32 $\pm 0.01^a$	21.54 $\pm 2.81^a$	0.04 $\pm 0.01^a$	0.22 $\pm 0.03^a$	0.82 $\pm 0.03^a$	4.85 $\pm 0.61^a$
MM2	5.53 $\pm 0.28^a$	90.23 $\pm 2.81^a$	7.95 $\pm 0.88^a$	1.82 $\pm 0.20^b$	Sand	1.15 $\pm 0.09^a$	1.60 $\pm 0.21^a$	2.77 $\pm 0.46^b$	26.30 $\pm 3.42^a$	0.06 $\pm 0.00^a$	0.28 $\pm 0.01^a$	1.20 $\pm 0.07^a$	8.02 $\pm 1.30^b$
MM3	5.80 $\pm 0.34^b$	80.61 $\pm 2.76^b$	15.82 $\pm 1.45^b$	3.57 $\pm 0.47^c$	Loamy sand	0.94 $\pm 0.11^a$	1.90 $\pm 0.35^a$	1.21 $\pm 0.08^c$	29.48 $\pm 1.63^a$	0.05 $\pm 0.00^a$	0.21 $\pm 0.05^a$	1.60 $\pm 0.01^b$	10.84 $\pm 1.72^b$
OP1	5.46 $\pm 0.41^a$	90.44 $\pm 3.25^a$	7.69 $\pm 0.94^a$	1.87 $\pm 0.21^b$	Sand	0.58 $\pm 0.07^b$	1.01 $\pm 0.07^b$	0.96 $\pm 0.02^c$	23.29 $\pm 2.61^a$	0.05 $\pm 0.01^a$	0.36 $\pm 0.02^b$	1.62 $\pm 0.04^b$	6.43 $\pm 0.95^a$
OP2	5.57 $\pm 0.61^a$	78.62 $\pm 1.02^b$	11.83 $\pm 1.07^c$	9.55 $\pm 1.48^d$	Loamy sand	1.31 $\pm 0.12^a$	2.25 $\pm 0.41^c$	0.61 $\pm 0.04^a$	26.46 $\pm 3.11^a$	0.07 $\pm 0.02^b$	0.25 $\pm 0.06^a$	1.60 $\pm 0.03^b$	6.80 $\pm 0.76^c$
OP3	5.21 $\pm 0.09^a$	90.57 $\pm 4.21^a$	6.14 $\pm 1.16^d$	3.29 $\pm 0.77^a$	Sand	0.76 $\pm 0.04^a$	1.31 $\pm 0.05^a$	0.55 $\pm 0.01^a$	17.34 $\pm 1.65^b$	0.04 $\pm 0.00^a$	0.27 $\pm 0.03^a$	1.63 $\pm 0.01^b$	8.00 $\pm 1.13^b$
AB1	5.85 $\pm 0.11^b$	90.81 $\pm 1.86^a$	5.75 $\pm 0.69^d$	3.44 $\pm 0.28^a$	Sand	0.38 $\pm 0.06^b$	1.07 $\pm 0.20^b$	0.30 $\pm 0.00^a$	22.47 $\pm 1.53^a$	0.06 $\pm 0.00^a$	0.28 $\pm 0.04^a$	1.20 $\pm 0.06^a$	6.42 $\pm 0.92^a$
AB2	5.93 $\pm 0.20^b$	92.34 $\pm 3.47^a$	5.91 $\pm 0.44^d$	1.75 $\pm 0.11^b$	Sand	0.59 $\pm 0.07^b$	1.01 $\pm 0.09^b$	0.35 $\pm 0.01^a$	27.86 $\pm 3.15^a$	0.05 $\pm 0.01^a$	0.24 $\pm 0.01^a$	0.82 $\pm 0.01^a$	5.60 $\pm 0.87^a$
AB3	6.60 $\pm 0.52^a$	88.62 $\pm 1.53^a$	10.11 $\pm 0.86^c$	1.27 $\pm 0.09^b$	Sand	0.62 $\pm 0.10^b$	0.65 $\pm 0.02^d$	0.50 $\pm 0.02^a$	22.01 $\pm 1.15^a$	0.04 $\pm 0.00^a$	0.21 $\pm 0.03^a$	0.80 $\pm 0.00^a$	4.11 $\pm 0.53^a$
OG1	4.33 $\pm 0.22^d$	60.58 $\pm 1.77^c$	30.45 $\pm 2.70^e$	8.97 $\pm 1.25^d$	Sandy loam	2.71 $\pm 0.83^c$	4.64 $\pm 0.73^c$	1.14 $\pm 0.08^c$	21.49 $\pm 4.17^a$	0.08 $\pm 0.02^a$	0.35 $\pm 0.07^b$	1.65 $\pm 0.03^b$	6.00 $\pm 1.25^a$
OG2	5.08 $\pm 0.08^a$	40.37 $\pm 0.95^d$	44.10 $\pm 2.13^f$	15.53 $\pm 2.16^e$	Silty loam	3.15 $\pm 0.66^d$	5.42 $\pm 0.88^c$	1.77 $\pm 0.05^c$	25.18 $\pm 3.01^a$	0.15 $\pm 0.03^b$	0.33 $\pm 0.03^b$	0.84 $\pm 0.05^a$	4.80 $\pm 0.81^a$
OG3	5.31 $\pm 0.14^a$	70.66 $\pm 1.20^b$	12.39 $\pm 1.51^e$	16.95 $\pm 1.74^c$	Sandy loam	0.83 $\pm 0.05^a$	1.38 $\pm 0.11^a$	0.65 $\pm 0.02^a$	24.16 $\pm 1.65^a$	0.10 $\pm 0.02^b$	0.30 $\pm 0.04^b$	0.40 $\pm 0.01^c$	7.64 $\pm 1.23^a$

Values with the same superscript on the same column were similar ($P > 0.05$)

Table 4. Mean (\pm SD) Heavy Metal Concentrations of Sediment Samples

Sample ID	As (mg/L)	Cd (mg/L)	Fe (mg/L)	Pb (mg/L)
MM1	ND	1.215 \pm 0.301 ^a	57.324 \pm 10.530 ^a	3.502 \pm 0.877 ^a
MM2	1.175 \pm 0.086 ^a	0.948 \pm 0.072 ^a	104.902 \pm 14.810 ^b	2.240 \pm 0.341 ^b
MM3	ND	1.413 \pm 0.438 ^a	130.231 \pm 23.720 ^c	4.311 \pm 0.826 ^c
OP1	1.283 \pm 0.250 ^a	2.523 \pm 0.197 ^b	95.022 \pm 21.164 ^b	3.640 \pm 0.512 ^a
OP2	ND	2.216 \pm 0.066 ^b	101.100 \pm 18.355 ^b	1.610 \pm 0.762 ^d
OP3	ND	1.094 \pm 0.350 ^a	128.804 \pm 31.742 ^c	1.725 \pm 0.477 ^d
AB1	ND	1.547 \pm 0.204 ^a	81.646 \pm 12.774 ^b	2.633 \pm 0.396 ^b
AB2	ND	2.106 \pm 0.087 ^b	92.551 \pm 10.851 ^b	1.947 \pm 0.425 ^c
AB3	1.291 \pm 0.335 ^a	1.210 \pm 0.074 ^a	110.383 \pm 19.386 ^b	7.462 \pm 0.861 ^f
OG1	ND	3.120 \pm 0.131 ^c	102.301 \pm 24.470 ^b	1.300 \pm 0.295 ^d
OG2	ND	2.409 \pm 0.088 ^b	121.174 \pm 25.310 ^c	2.324 \pm 0.814 ^b
OG3	ND	2.336 \pm 0.276 ^b	159.707 \pm 41.192 ^c	1.618 \pm 0.229 ^d
ISQG(mg/kg)	7.24	0.7	-	30.2

ISQG = Interim Sediment Quality guidelines (CCME, 1999); ND = not detected; NA = not available

Values with the same superscript on the same column were similar ($P > 0.05$)

Table 5. Contamination factors, Igeo and PLI values

Locations	CF for Metals			PLI	Igeo for Metals		
	As	Cd	Pb		As	Cd	Pb
MM1	-	1.736	0.116	0.449	-	0.210	-3.699
MM2	0.162	1.354	0.074	0.253	-3.211	-0.147	-4.351
MM3	-	2.019	0.143	0.537	-	0.429	-0.157
OP1	0.177	3.604	0.121	0.426	-3.083	1.264	-3.626
OP2	-	3.166	0.053	0.410	-	1.078	-4.837
OP3	-	2.233	0.057	0.357	-	0.574	-4.718
AB1	-	2.210	0.087	0.438	-	0.559	-4.108
AB2	-	3.009	0.064	0.577	-	0.419	-4.540
AB3	0.178	1.728	0.247	0.424	-3.071	0.204	-2.599
OG1	-	4.457	0.043	0.438	-	1.571	-5.108
OG2	-	3.441	0.077	0.515	-	1.198	-4.293
OG3	-	3.337	0.054	0.424	-	1.154	-4.796

Conclusion: This study has shown that sediment samples collected from the four locations on Orashi River were unpolluted in terms of TPH and the texture of most bed sediment samples was sandy. Mean As and Pb concentrations were lower than the soil quality guidelines (SQG). However, mean Cd concentrations

were higher than the guidelines in all sites and contamination factors also indicated moderate to considerable Cd contamination in the sediments. Geo-accumulation indices (Igeo) also indicated unpolluted to moderately polluted Cd status for the samples.

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