DISTRIBUTION OF HEAVY METAL CONCENTRATION IN THE WATER AND RIVERBED SEDIMENT OF PUSSUR RIVER

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ABSTRACT

Pussur River, being one of the main navigable channels of Mongla Port, requires regular dredging that generates massive volumes of sediment now indiscriminately dumped, leading to environmental consequences. This current study contrasts environmental and geotechnical characteristics of Pussur River dredged sediments with a view to establishing contamination levels and recommending potential reuse practices. Sediments collected from dumpsite and riverbed sites were analyzed for heavy metals (Ni, Zn, Pb, Cu, Cr, Cd) and other important geotechnical factors. The results indicated that river water was within the standard limits of international standards for all metals except Cd and Pb, which exceeded safety limits. Sediments contained elevated metal content with the Metal Pollution Index (MPI) indicating extreme to severe contamination headed by Ni, Mg, and Zn. Geotechnically, the material was of class poorly graded fine sand (SP) with a fineness modulus of 0.52–0.81, maximum dry density 14.85 kN/m³, and optimum water content 14.5%. High organic matter and salinity were greater than the limit for agriculture or brick use. However, the sediment has potential for utilization in geotechnical engineering such as land reclamation, embankment, and road construction following salinity treatment. The study emphasizes sustainability in the treatment of dredged material, turning waste into a resource for economic development and infrastructure.

Keywords: **:** *Pussur River, Riverbed sediment, Heavy metals, Sustainable management.*

1. INTRODUCTION

Rivers are lifelines that offer freshwater supply, irrigation, biodiversity, and navigation. In a river-based nation like Bangladesh, the rivers are crucial to its livelihood and economy. Continuous erosion and sedimentation reduce river depths, which require continuous dredging to maintain navigability (Rahman & Ali, 2024). Around 80 million cubic meters of material are dredged from Bangladeshi rivers annually (Wasim & Nine, 2017) .However, indiscriminate disposal of dredged sediments has the tendency to cause environmental degradation, degradation of water quality, and disturb the ecosystem (Wasim & Nine, 2017). Dredged sediments, though generally considered waste materials, are reusable as valuable secondary raw construction and land reclamation materials (Bose & Dhar, 2022). Sediment management promotes sustainable reuse instead of disposal (Jan & Mir, 2018). Sedimentation also affects reservoir storage and flood management, necessitating proper dredging and disposal site location in terms of hydrodynamic and environmental parameters (Rahman et al., 2023).

The Pussur River, located near the Sundarbans mangrove forest ecosystem, is subject to intense industrial and municipal pollution due to cement, textile, and oil industries and agricultural runoff leading to heavy metal pollution (Shil et al., 2017). Although it is crucially significant, there is little research to examine its sediment quality. Heavy metal distribution and geotechnical characteristics of dredged materials need to be known in order to assess ecological risk and potential reuse. Practically, most dredged sediment is dumped on the nearby river, agricultural land, and aquaculture indiscriminately, resulting in resedimentation, land loss, and environmental hazards (Shome et al., 2025).

The study evaluates the geotechnical and environmental characteristics of Pussur River dredged sediments to determine contamination levels and render them appropriate for engineering purposes. The findings aim at promoting sustainable sediment management through the creation of dredged material as waste to product, promoting environmental protection as well as infrastructure growth.

2. METHODOLOGY

2.1 Sample Collection

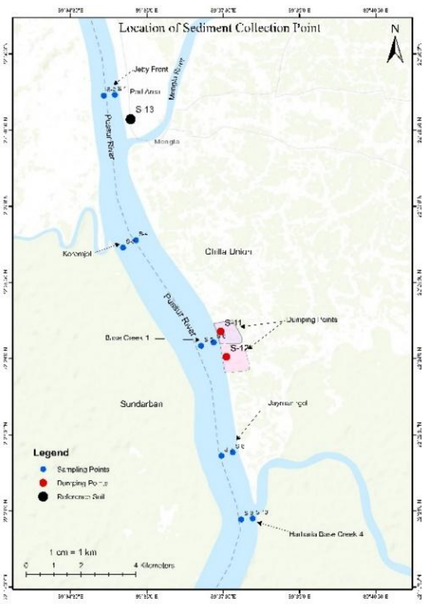


Figure 1. Sampling points for soil samples Pussur River, Mongla

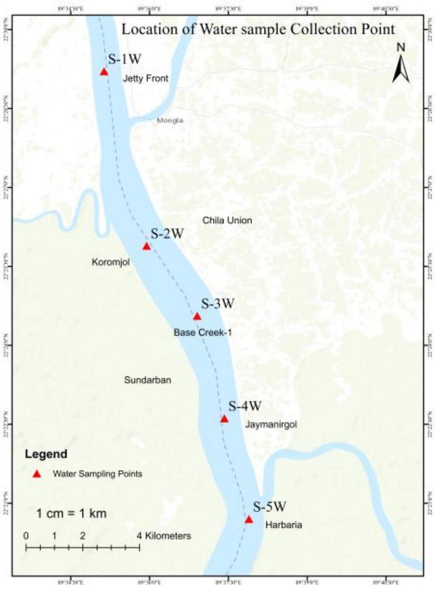


Figure 2. Sampling points for water samples in Pussur River, Mongla

Sediment samples were collected on June 29, 2024, from dumping locations, the bed of the Pussur River, and a reference station near Mongla Jetty. The front of the jetty, Koromjol, Base Creek-1, and Base Creek-4 (Harbaria) were sampling stations. Sediments were collected by a Van Veen grab sampler and preserved in labelled polythene bags. The locations were recorded using GPS (My GPS Location App). Samples S-1 to S-10 were taken from the riverbed, S-11 and S-12 from disposal sites, and S-13 as the reference sample. River water samples (S-1W to S-5W) were also taken close to the respective soil sampling points in June 2024. Figure 1 and 2 shows the sediment and water sampling points.

2.2 Preparation of Samples

2.2.1 Sediment and water samples for heavy metal determination

Sediment samples were air-dried, oven-dried at 105 ± 5 °C for 24 h, and sieved through a #200 mesh. About 0.5 g of each sample was digested in 3 mL HCl and 9 mL HNO_3 (ratio 1:3) using a microwave digestion system(Bettinelli et al., 2000). Water samples (50 mL each) were also digested with conc. HNO_3 following (EPA 3015A, 2007). Samples after digestion were filtered (Whatman filter, No. 42) and made up to 50 mL for ICP-MS analysis at the Modern Equipment and Research Center, KUET, to determine concentrations of Zn, Cu, Pb, Ni, Cr, and Cd. The maximum permissible limits of heavy metals in soils are presented in Table -1(Ediene & Umoetok, 2017).

Table-1. Maximum permissible limits for Heavy metals in soil (mg/kg)

Heavy metals	Italian legislation (urban environment)	EU regulation (plant-growing media)	UK-GLC (landfill cover/ horticulture)	UK-GLC (land reclamation/filling)	WHO
Zn	150	5000	250	500	80
Cu	120	200	100	-	30
Cd	2	1.5	0.5	3	3
Cr	-	180	6.4	400	100
Pb	100	120	500	1000	100
Ni	120	50	250	500	80

2.3 Chemical Properties Determination of Soil

2.3.1 Salinity determination

The salinity of seven soil samples was determined by chloride concentration analysis at the Environmental Laboratory of KUET. Each soil sample was mixed with distilled water in a 1:5 ratio and left for 24 hours. The supernatant water was then collected and used for testing. For each sample, 20 ml of the extract was titrated with $AgNO_3$ using $K_2Cr_2O_7$ as an indicator until a reddish color appeared, indicating the endpoint.

2.3.2 Organic matter determination

Soil samples were sieved through a #40 sieve and placed in pre-weighed porcelain bowls. The samples were ashed in a furnace at 550°C for 4–5 hours, and the remaining weight was recorded to determine organic matter content after complete carbon combustion (Heiri et al., 2001).

2.3.3 Fe and Mg

The concentration of these two compounds of 13 soil samples were measured in the Modern Equipment and Research Center, KUET. The test results were received after they examined the materials.

2.4 Quantification of Soil Heavy Metal Contamination/Pollution Index (MPI)

Table -2. Interval of contamination/pollution index of heavy metals in soil and its significance

MPI	Significance	Remarks
<0.1	Very slight contamination	No negative effect on soil, plant and environment
0.10-0.25	Slight contamination	"
0.26-0.5	Moderate contamination	"
0.51-0.75	Severe contamination	"
0.76-1.00	Very severe contamination	"
1.1-2.0	Slight pollution	Will pose a negative effect on soil, plant and the environment
2.1-4.0	Moderate pollution	"
4.1-8.0	Severe pollution	"
8.1-16.0	Very severe pollution	"
>16	Excessive pollution	"

The Metal Pollution Index (MPI) was calculated following (Lacatusu, 1998) as the ratio of metal concentration in each soil sample to that of the reference (control) soil. MPI indicates the degree of heavy metal contamination and helps assess potential impacts on soil quality, plants, and the surrounding ecosystem. Table -2. shows the interval of contamination/pollution index of heavy metals in soil and its significance (Lacatusu, 1998).

2.5 Geotechnical Properties of Soil Samples

2.5.1 Grain size analysis

Grain size distribution of the soil samples was determined using mechanical sieve to classify soil and evaluate its engineering properties. The test followed ASTM D6913. Due to the shortage of samples, two samples are mixed together and then tested.

2.5.2 Standard proctor compaction test

The Standard Proctor Test was conducted following ASTM D698 to determine the optimum moisture content (OMC) and maximum dry density (MDD) of mixed soil samples (~3 kg) collected from riverbed and dumping sites. Soil was compacted in a cylindrical mold in three layers, each receiving 25 blows from a 10 lb hammer dropped from 457 mm height. Tests were performed at varying moisture contents (6%–24%), and the compaction curve was plotted to identify MDD and OMC.

3. RESULTS AND DISCUSSIONS

3.1 Concentration of Heavy Metal in Soil Samples

Concentrations of heavy metals (Cd, Cr, Cu, Pb, Ni, and Zn) in Pussur riverbed sediments at 13 stations were compared with various international soil quality guidelines. The results showed that all measured levels of Cd (0.476 to 0.569 mg/kg) were almost within the permissible limits. Chromium levels ranged from 8.87 to 22.4 mg/kg, which exceeds the standard limits set by the UK-GLC. Consequently, this Cr parameter can pose a negative impact for horticulture. Lead content (7.06 to 15.3 mg/kg) was significantly below all acceptable levels. Copper content (3.23 to 14.3 mg/kg) and zinc content (14.3 to 54.4 mg/kg) were also significantly lower than the tolerable limits according to all the mentioned standards. However, the nickel content at location S5 (92.6 mg/kg) was greater than the WHO limit of 80 mg/kg and EU level of 50 mg/kg, indicating ecological risk. In general, however, sediment quality at the majority of the sites appears to be within acceptable limits, though the very high concentration of nickel at certain sites may necessitate careful monitoring and localization of probable anthropogenic sources.

Table-3. Heavy metal concentration in sediment samples of Pussur River

	Concentration(mg/kg)					
Site	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
S1	0.476	8.87	6.37	71.9	13.5	53.3
S2	0.535	9.87	5.68	23.6	7.51	14.3
S3	0.492	17.9	10.5	39.1	8.37	22.5
S4	0.496	22.3	13.2	48.1	10	30.6
S5	0.504	19.3	14.2	92.6	15.3	54.4
S6	0.492	18.9	12.3	42.3	13.8	27.3
S7	0.502	19.1	12.7	42.5	10.1	25.3
S8	0.569	22.4	14.3	47	12.5	31.9
S9	0.484	17.3	11	42	9.99	23.3
S10	0.498	21.8	12.3	47.4	12.4	25.1
S11	0.478	10.6	3.23	26.1	7.06	18.6
S12	0.49	12.8	7.07	29.8	7.42	17.5
S13R	0.506	13.3	7.43	27.1	11	26.4

3.2 Concentration of Heavy Metal in Water Samples

The concentrations of heavy metals (Cd, Cr, Cu, Ni, Pb, and Zn) in water samples collected from five sampling stations (S-1W to S-5W) of the Pussur River in Mongla were compared with standard values of the Environmental Conservation Rules (ECR, Bangladesh) and USEPA guidelines. Cadmium concentrations at all sampling points ranged from 0.00462 to 0.00555 mg/kg. Although these values were higher than the ECR limit of 0.003 mg/kg, they were only just at or below the USEPA threshold value of 0.005 mg/kg, indicating potential cadmium contamination. The chromium values ranged from 0.0247 to 0.0347 mg/kg, still below both the ECR (0.05 mg/kg) and USEPA (0.1 mg/kg) limits. Copper concentration (0.0135–0.028 mg/kg) was significantly less than the tolerable levels (1.5 mg/kg for ECR and 1.3 mg/kg for USEPA), which shows Cu-associated contamination is negligible. Nickel content ranged from 0.0254 to 0.0658 mg/kg and was within ECR and USEPA standards (0.05 and 0.1 mg/kg respectively), though a shade more than the ECR limit at site S-5W. Lead levels (0.0519–0.0696 mg/kg) were well in excess of both ECR's admissible values (0.01 mg/kg) and

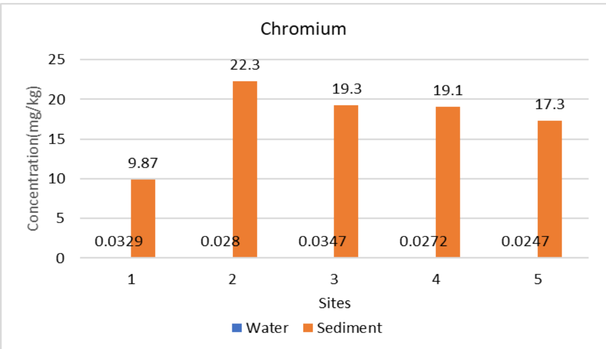
USEPA's (0.015 mg/kg), signifying widespread contamination by lead at all sample points. Zinc (0.123–0.189 mg/kg) was well below the acceptable 5 mg/kg standard prescribed by both norms. Overall, the findings reflect relatively low levels of Zn, Cu, and Cr in water samples but elevated levels of Pb and Cd at all stations and of Ni at some stations that may have ecological and public health consequences worthy of further investigation and remedial action.

Table-4. Heavy metal concentration in water samples of Pussur River, Mongla

	Concentration(mg/kg)					
Site	**Cd**	**Cr**	**Cu**	**Ni**	**Pb**	**Zn**
S-1W	0.00555	0.0329	0.0226	0.0356	0.0634	0.157
S-2W	0.00485	0.028	0.0151	0.027	0.0566	0.123
S-3W	0.00494	0.0347	0.0225	0.0317	0.0696	0.189
S-4W	0.00462	0.0272	0.028	0.0254	0.0519	0.144
S-5W	0.00484	0.0247	0.0135	0.0658	0.059	0.181
ECR	0.003	0.05	1.5	0.05	0.01	5
USEPA	0.005	0.1	1.3	0.1	0.015	5

3.3 Comparison of heavy metal concentration between sediments and water samples

The results from the six graphs consistently demonstrate a fundamental principle in environmental science, sediments act as a significant sink for heavy metal contamination. For all metals analyzed (Zn, Pb, Ni, Cu, Cd, Cr), the concentrations detected in the sediment samples are orders of magnitude higher than those found in the corresponding water samples from the nearby sites. From this comparison it is clear that, Pussur river water is safer than riverbed sediment with respect to heavy metal contamination.



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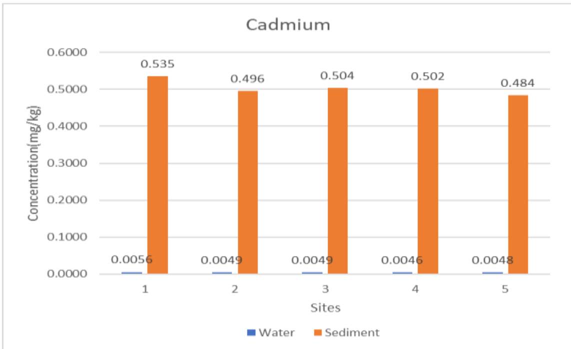

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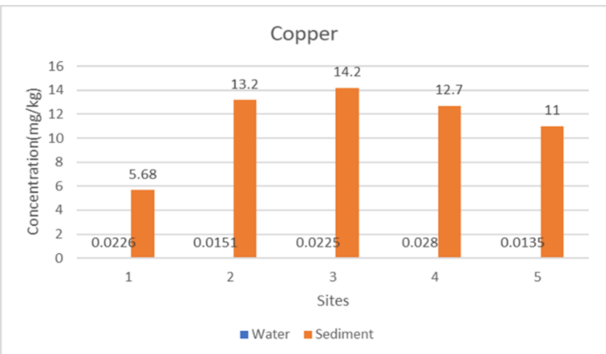

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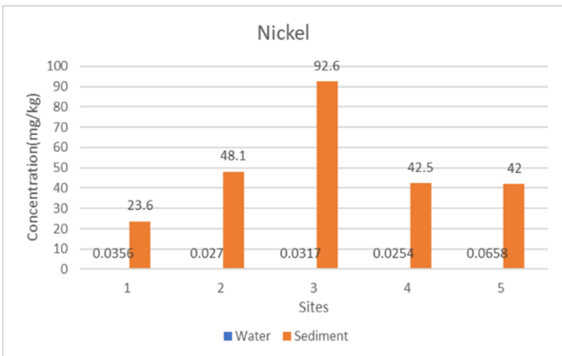

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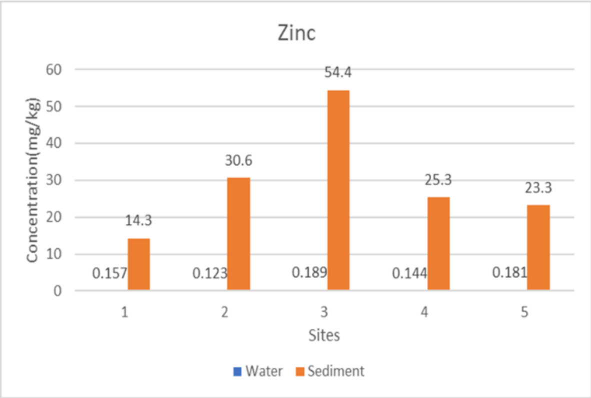

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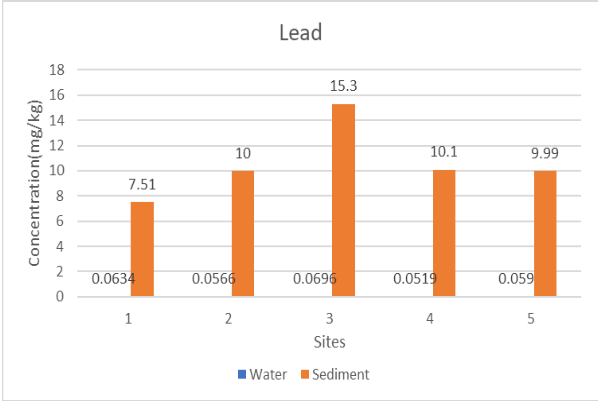

(f)

Figure-3. Comparison of the (a) Cr, (b) Cd, (c) Cu, (d) Ni, (e) Zn and (f) Pb concentration between sediment and water samples

3.4 Pollution Index (MPI) of Heavy Metals in Soils

The presented formula (Lacatusu, 1998) was used in order to calculate the extent to which the sediment was contaminated or polluted and graded as the soils are moderately contaminated to very moderately. It is evident from the data shown in appendix that among the heavy metals determined in Mongla Pussur River sediments, Nickel (Ni) is the most polluting one. The Ni pollution indices, as determined from measurements on several sample locations, vary between 0.87 and 3.42 on the pollution index (MPI), representing very severe contamination to moderate pollution. With a varying MPI of 0.80 to 2.05, Magnesium (Mg) is the second most prominent pollutant after Ni. Mg pollution indices are classified as representing very severe contamination to moderate pollution in all testing locations, the same as Ni. Next in line for pollution severity is Zinc (Zn), with MPI values ranging from 0.54 to 2.06, indicating severe contamination to moderate pollution levels. Other heavy metals such as Lead (Pb), Chromium (Cr), Copper (Cu), Cadmium (Cd) and Iron (Fe) also contaminate, but their MPI values frequently fall within the slight to moderate pollution intensity range. Briefly, the sequence of heavy metals accountable for pollution based on their MPI values is Ni > Mg > Zn > Cu > Fe > Cr > Pb > Cd.

3.5 Geotechnical Properties of Sediment Samples

3.5.1 Grain size analysis

The grain size distributions of the river bed soils and the disposal site soils were done in the laboratory and compared with each other (Figure-4). The percent of dredged soil passing through the No. 200 sieve varied from 2.5% to 5.5%. In engineering practice, coarse-grained soil particles have grain sizes greater than 0.075 mm, which is the grain size at the boundary between silt and sand (D18 Committee, n.d.). Sandy soils are used as building material and as a base for foundations (Keaton, 2018). The fineness modulus (FM) of the soils varied from 0.52 to 0.81, which satisfied the minimum requirement of 0.50 for land use for land development set by the Public Works Department of Bangladesh. As shown in Table-5, according to the Unified Soil Classification System (USCS), 94.6% to 97.5% of soil samples had particle sizes of 0.075 to 0.425 mm and could be classified as fine sand.

Table-5. Sample description and USCS classification

Sample ID	Percent of fine sand with particle size of 0.075 to 0.425 mm (%)	Percent of coarse sand with particle size of 0.425 to 2.000 mm (%)	FM	Soil type
S-1 & 2	95	-	0.56	Fine sand
S-3 & 4	95.4	-	0.53	Fine sand
S-5 & 6	96.5	-	0.62	Fine sand
S-7 & 8	94.6	-	0.52	Fine sand
S-9 & 10	97.5	-	0.61	Fine sand
S-11	97.2	-	0.77	Fine sand
S-12	96.8	-	0.81	Fine sand

Table-6. Suitability rating for Pussur River sands

Sample ID	FM	D10 (mm)	D30 (mm)	D60 (mm)	SN	Rating
S-1 & 2	0.56	0.08	0.11	0.14	25	Fair
S-3 & 4	0.53	0.081	0.1	0.145	27	Fair
S-5 & 6	0.62	0.079	0.103	0.147	28	Fair
S-7 & 8	0.52	0.08	0.11	0.15	31	Poor
S-9&10	0.61	0.083	0.11	0.15	30	Poor
S-11	0.77	0.08	0.12	0.18	27	Fair
S-12	0.81	0.082	0.13	0.22	29	Fair

Table-6. shows the calculated suitability rating for soils collected from the river bed and disposal sites. The suitability number (SN) of the dredged sand from disposal sites is 27 and 29, corresponding to the rating of fair. Again, for the riverbed soils, the suitability number (SN) varied from 25 to 31, corresponding to the ratings of poor to fair.

3.5.2 Soil classification

Table-7. shows several indices of the soils that are obtained from particle size distribution analysis. The indices include FM, the coefficient of uniformity (Cu), coefficient of curvature (Cc). The Cu values of the soils were in the range of 1.75 to 2.68, indicating that the soil samples were not uniform sand. A greater Cu resulted in a larger range of particle sizes in soil. According to USCS classification, all the soil samples collected from the river bed and the disposal site fell in the SP group category and were poorly graded.

Table-7. Classification of sand based on uniformity and gradation coefficients (USCS)

Sample Id	FM	Cu	Cc	USCS classification	
				Group Symbol	Group Name
S-1 & 2	0.56	1.750	1.080	SP	Poorly graded sand
S-3 & 4	0.53	1.790	0.851	SP	Poorly graded sand
S-5 & 6	0.62	1.861	0.914	SP	Poorly graded sand
S-7 & 8	0.52	1.875	1.008	SP	Poorly graded sand
S-9 & 10	0.61	1.807	0.972	SP	Poorly graded sand
S-11	0.77	2.250	1.000	SP	Poorly graded sand
S-12	0.81	2.683	0.937	SP	Poorly graded sand

3.5.3 Compaction properties

Figure-4. shows the compaction curve for the mixed soil from the 12 samples. The maximum dry density (MDD) was found 14.85 (kN/m^3), and the corresponding optimum moisture content (OMC) was found 14.5%.

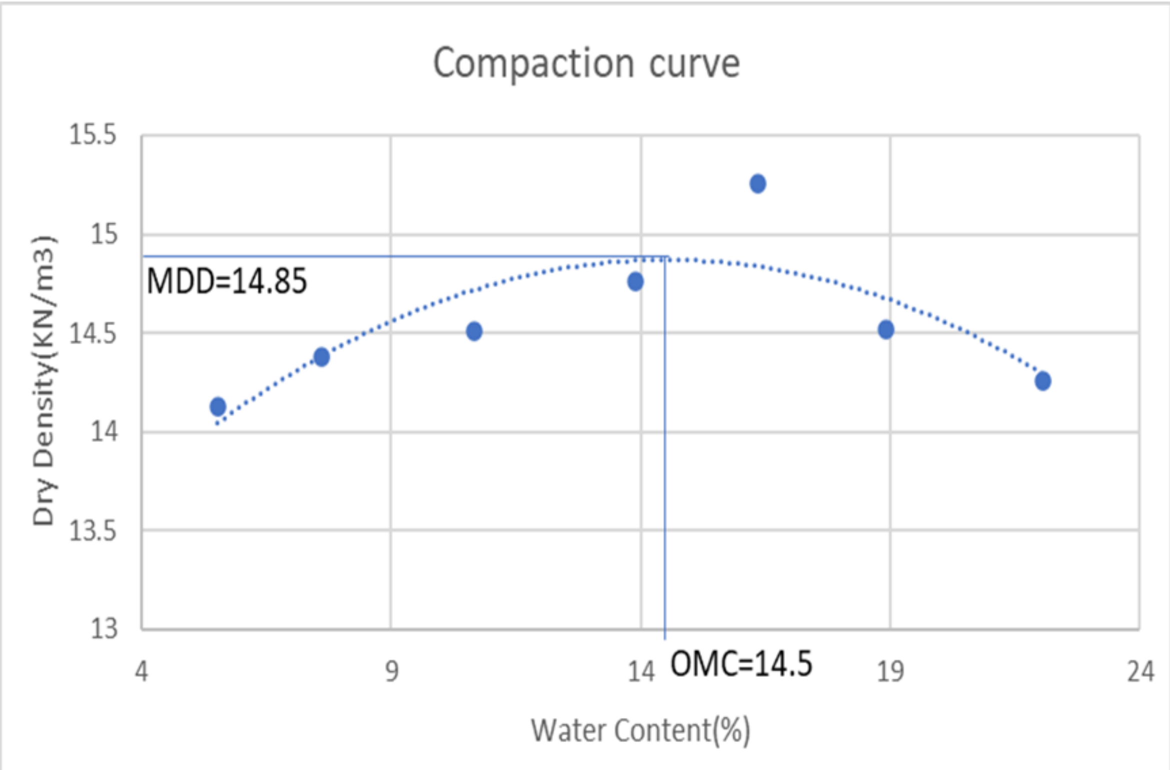

Figure-4. Compaction curve of the mixed soil

3.6 Chemical Properties Test

3.6.1 Chemical Properties of Soil Samples

Table- 8. Chemical properties of soil samples

Sites	Chemical parameter concentration (%)			
	Fe	Mg	Organic matter	Salinity
S-1 & 2	1.57	0.01	**3.23**	0.071
S-3 & 4	1.40	0.02	**3.51**	0.045
S-5 & 6	1.56	0.07	**3.07**	0.013
S-7 & 8	2.07	0.02	**5.93**	0.077
S-9 & 10	1.34	0.02	**3.98**	0.039
S-11	1.15	0.03	**2.21**	0.004
S-12	2.03	0.05	**2.13**	0.007
Allowable limit for brick manufacture (%) (Aziz, 1995; Baspinar et al., 2010)	8	5	1	-

*N.B. Bolded numbers mean that they are higher than the minimum allowed value

Chemical properties of the sediment samples were analyzed to assess their quality to be utilized in the production of bricks. Organic matter, Fe, Mg, and salinity were compared with standard guidelines of (Aziz, M.A., 1995) and (Baspinar et al., 2010). Ranges of Fe and Mg were 1.15–2.07% and 0.01–0.07%, respectively, and they are within acceptable standards to use in the production of bricks. However, the organic matter content (2.13–5.93%) exceeded the maximum acceptable limit of 1%, and therefore the material was not acceptable in its original form. Salinity analysis showed high levels of chlorides, particularly for riverbed sediments (S-1 to S-10) compared to disposal areas (S-11 and S-12). Salinity decline in disposal site sediments is a result of dilution, leaching, settling, and mixing processes during dredging. These findings indicate that while mineral composition is good for potential reuse, high organic matter and salinity levels limit direct application for brick manufacturing without treatment.

4. CONCLUSION

This study evaluated the levels of heavy metals in water and sediments of Pussur River, Bangladesh dredged material and geotechnical and chemical properties of sediment and water to determine their extent of contamination and potential for reuse. Results indicated that sediments are considerable sinks for heavy metals and have overall much greater contamination than water. Nickel (Ni), Magnesium (Mg), and Zinc (Zn) proved to be dominant pollutants with MPI values indicating slight to severe contamination. Increased contents of metals in riverbed sediments compared to disposal sites reflect concurrent sources of contamination like industrial effluent, petroleum, municipal effluent, and factory and steel mill fumes of the surrounding areas of Khulna. Geotechnical analysis classified the dredged sediment as fine sand, good for land reclamation, road, and embankment construction. Rash dumping has to be replaced by a quantitative management system to transform dredged sediments from waste material to productive engineering resources.

Declaration of Use of AI

The authors declare that artificial intelligence (AI) tools were used solely for language editing and paraphrasing purposes in the Introduction and Methodology sections of this manuscript. Specifically, ChatGPT and QuillBot were utilized to improve clarity, grammar, and readability of the text. No AI tools were used in the research design, data collection, laboratory experiments, data analysis, interpretation of results, or preparation of figures and tables.

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