ANALYSIS ON PHYSICAL AND CHEMICAL PROPERTIES OF DREDGED MATERIAL IN PUSSUR RIVER OF BANGLADESH

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ABSTRACT

Dredged material in Bangladesh is a valuable resource due to its strength, potential uses, and potential for land reclamation, filling material, landfill cover, horticultural purposes, and plant growing media. However, its physical, geotechnical, and environmental properties must be studied before use in a potential field. The Pussur River in Bangladesh is siltation-prone and requires significant capital and maintenance dredging for the navigational aspect of Mongla Port (MP). Due to restrictions on industrialization within 10 km of the Sundarbans, lands on both sides of the river downstream are mainly used for fish production. As new industries and urbanization are developing rapidly, there is a demand for dredged material about five kilometers upstream of MP.

Sand mining from nearby rivers is a common practice for land development, but due to the distance between dredging and disposal locations, land development companies are not interested in using/carrying the dredged material from dumping stations located at the downstream locations of MP. As fishponds and cultivable land are reducing, there may not be available land for the disposal of dredged material if already developed lands are not vacated. Therefore, it is necessary to use the dredged sediment for other beneficial purposes instead of dumping it on two sides of the river. This study examines the use of dredged soil samples from disposal areas near the Pussur River, assessing their suitability for use as backfill material for retaining structures, sand compaction piles, and other similar projects. Laboratory compaction tests are used to calculate the percent compaction and molding water content needed for engineering qualities in foundation soils. The Direct Shear Test is an experimental approach used in geotechnical engineering to determine the shear strength of soil materials.

The study examined the geotechnical and chemical properties of dredged soil, including grain size distribution, shear and compaction properties, heavy metal concentration, salinity, and organic matter content. The results showed that the concentrations of Al, Fe, Mg, SiO2, and Organic Matter were well below the allowable limit for brick manufacturing, but the Silica content was well above the limit of 55%. The heavy metal concentration in river bed sediment at the harbor area of Pussur River were found to be higher than undredged areas. The permissible limits of heavy metals in soil vary based on its field of use, with the UK-GLC recommending lower limits for Zn, Pb, Cu, Cd, and Ni for land reclamation or reuse of material for filling purposes. The study also examined the geotechnical properties of dredged sand in the harbor area of Pussur River, focusing on its potential for silver contamination. The heavy metal concentration in the riverbed sediment was found to be higher than other materials like Kustia and mixed sand. The suitability rating for Pussur, Kustia, and mixed sands varies from 30 to 33, ranging from 'Poor to Fair'. The study highlights the importance of addressing the potential contamination of riverbed sediments in the construction industry.

Keywords: *Dredged Sand, Pussur River, Grain Size Distribution, Heavy Metal Concentration, Filling Material.*

1. INTRODUCTION

The erosion process of riverbanks and riverbeds produces sediment, which can deposit on other parts of a water body, reducing the depth of the river. In Bangladesh, dredging is an absolute measure to maintain the navigability of rivers, with about 80 million cubic meters of material dredged from various rivers annually. The dredging and disposal process has a significant effect on the marine environment (Wasim and Nine, 2017). Two general alternatives for dredged material placement are disposal and beneficial use in various geotechnical applications.

Siltation of water reservoirs with sediments is an important problem in water management due to the reduction of the basin's accumulation capacity and the utilization of sediment waste extracted from water reservoirs. Dredging may affect the physical environment by changing bathymetry, current velocity, and wave conditions. Management of dredged material is difficult due to the scarcity of land. However, there is scope for treating the dredged material as resources for beneficial use. Beneficial uses of dredged material should be pursued to the maximum extent practicable. However, before using the dredged material in a potential field, its physical, geotechnical, and environmental properties are needed to be studied. Dredged material may contain heavy metals originating from natural or anthropogenic sources. Heavy metals are considered one of the major sources of soil pollution (Jiwan and Ajay, 2011). The long-term leaching of heavy metals from landfill areas can contaminate nearby aquifers and surface water (Berenjkar et al., 2019). Moreover, the use of dredged material can be considered if it becomes economical compared to the other available options. A suitable reuse plan of dredged material in coastal areas of Bangladesh, where the demand is less, may reduce the expenditure on dredging. If beneficial usage is not possible and the dredged material is uncontaminated, it can be disposed of at sea in certain conditions. Sediment stability is another important condition that needs to be considered in the selection of dumping sites. If the disposal location for dredged material is not chosen properly for the prevailing hydrodynamic conditions and sediment characteristics, substantial volumes of disposed material could find their way back into the port operational areas resulting in a loss of depth.

Dredged material is increasingly being regarded as a resource rather than a waste (Mir, 2015). It can be used for land reclamation, filling material, landfill cover, horticultural purposes, or plant growing media. The stability or strength of dredged sand can also be improved by adding cement or lime at a certain ratio. However, before using the dredged material in a potential field, its physical, geotechnical, and environmental properties must be studied. Pussur River, which is a major river in Bangladesh, is in its southwestern part. This river is very much siltation-prone (Rahman and Ali, 2022; Rahman et al. 2023) and requires huge capital and maintenance dredging for the navigational aspect of Mongla Port (MP). Due to restrictions on industrialization within 10 km of the Sundarbans, the lands on both sides of the Pussur River downstream of MP are used mainly for fish production. As there is no scope for alternative disposal, MP is filling fish production and cultivable lands, reducing productive lands and negatively impacting people's livelihood. Therefore, it is necessary to use the dredged sediment for other beneficial purposes instead of dumping it on two sides of the river. In this research, the geotechnical and environmental characteristics of dredged material have been investigated to explore the potential use in different engineering applications.

2. STUDY AREA AND METHODOLOGY

2.1 Study Area

Bangladesh has 24,000 km of rivers, streams, and canals covering 7% of the country's surface (Ali, 2013). The country is connected by a complex network of waterways that reaches its extensive size during the monsoon period. Only 5,968 km of these waterways are navigable for mechanized vessels during the monsoon period, shrinking to 3,865 km during the dry period (Hasan et al., 2017). Bangladesh Inland Water Transport Authority (BIWTA) and Bangladesh Water Development Board (BWDB) are responsible for dredging in Inland Rivers, while three sea ports, Chattogram Port Authority (CPA), Mongla Port Authority (MPA), and Payra Port Authority (PPA), are responsible for their navigation routes.

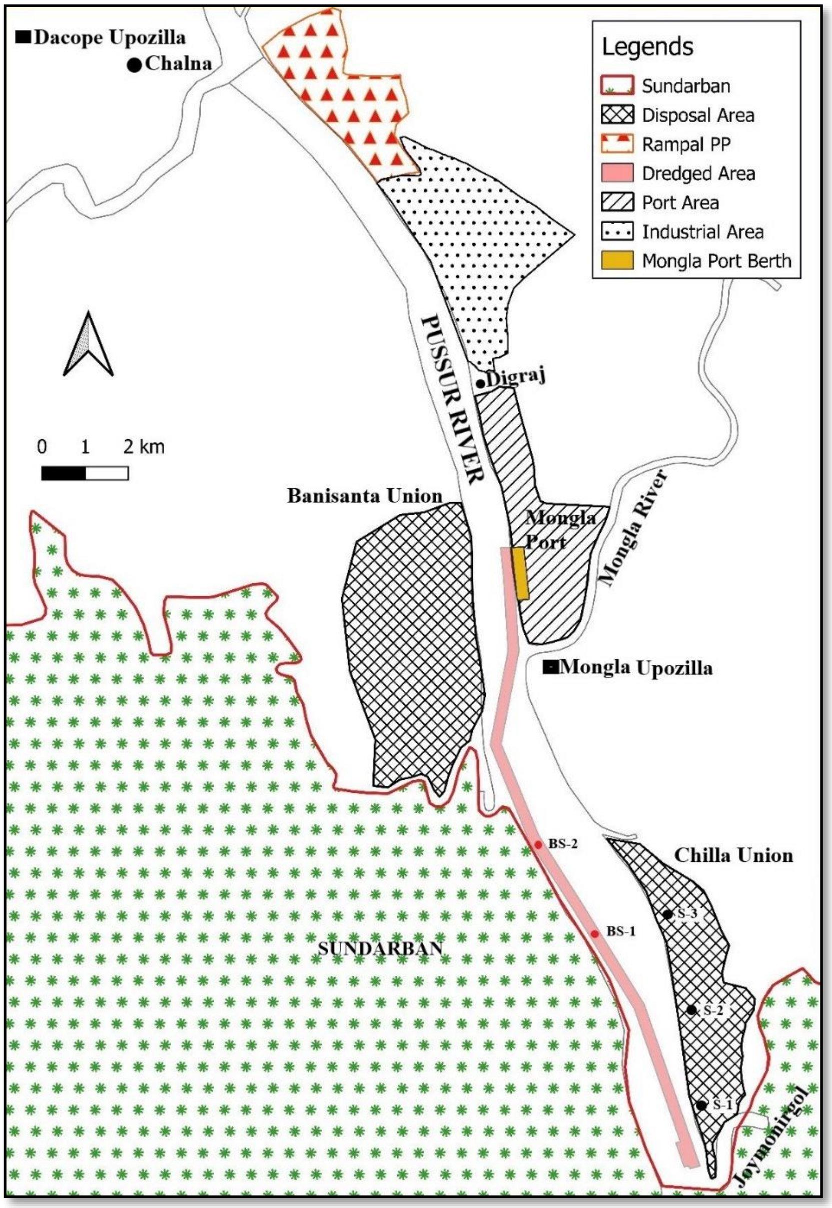

Figure 1: Study area and sample collection locations.

The yearly dredged quantity of these agencies is approximately 80 million cu.m. To dispose of these materials, 2665 hectares of land are required each year. Government agencies have limited free land for dredged material disposal, with private low land being used. However, there is demand for dredged material for various beneficial purposes, but rural areas, particularly in the 'Prohibited Industrialization' area like Mongla, do not want to develop their land with dredged material. In the southeast coastal region of Bangladesh, the Pussur River and Ghasiakhali channel (Mongla River) require continuous maintenance dredging. Both agencies face a common problem of land for dredged material disposal. The Pussur River is selected as the study area to investigate its sediment characteristics for the beneficial reuse of dredged spoil as part of sustainable sediment management.

2.2 Methods and Materials

The study focuses on the physical and chemical properties of dredged material, particularly for brick production and use in concrete. Samples were collected from the dredging area and disposal area on the bank. Grain size distribution and chemical properties are crucial, as dredged material may contain excess chloride and sulphate, which can be harmful when used as a replacement for fine aggregate in concrete. Grain size analysis is also used to assess the material's suitability for land development. Mir et al. (2016) reported that physical tests are necessary to assess the reuse of dredged material. For land development purposes, Grain size analysis, Optimum Moisture Content, Maximum dry density, and direct shear strength properties are essential. Heavy Metals (HMs) presence is also a significant factor. The study collected dredged soil samples from three disposal Compartments near the Pussur River. The clayey particles were removed through washing, reducing the volume of the collected samples. Laboratory tests were performed on five soil samples, including three dredged soil samples, local sand Kustia sand, and a mixture of dredged and Kustia sand. The samples collected and tested in this study are described in Table-1 and the sample collection location shown in Figure-1.

Table 1: Description of the samples

Sample ID	Description	Remarks
S-1	Dredged Sand collected from Disposal Compartments S-1	Collected sand has been washed to remove the clayey particles and about 25% volume of the collected sample has been reduced
S-2	Dredged Sand collected from Disposal Compartments S-2	
S-3	Dredged Sand collected from Disposal Compartments S-3	
S-4	Local (Kustia) Sand	Popular local sand in Khulna Division
S-5	A mixture of Kustia and Dredged Sand	50% Kustia sand and 50% dredged Sands
BS-1	River Bed sample collected from undredged area	Heavy metal concentrations were measured for these two samples collected from the riverbed
BS-2	River Bed samples collected from the dredged area	

The soil gradation was assessed using ASTM C136, with the suitability number (SN) being a crucial factor in determining the suitability of sandy soil for these purposes. Soil pollution by heavy metals is a significant concern globally due to its direct and indirect impact on human health. In reclaimed land filled with dredged sediments, agricultural practices may lead to uptake of heavy metals by crops and plants, and ingestion by farm animals may lead to metal poisoning in food. To assess the presence of heavy metals, samples were collected from two sites at the river bed, dredged and un-dredged, in the harbor area of Pussur River.

The Standard Proctor Compaction Test and the Modified Proctor Compaction Test are used to measure a soil's level of compaction by determining its maximum dry density and ideal moisture content. The Direct Shear Test is an experimental approach used in geotechnical engineering practice and research to determine the shear strength of soil materials. Bangladesh, a riverine country, has numerous different sand sources available, with the majority used in construction projects due to their availability and lower cost. The native sands in Bangladesh primarily come from places like Sylhet, Kustia, Feni, Rangpur, and Panchagarh. The characteristics and functionality of the sand from the Pussur River and that from Kustia are contrasted in this study.

3. EXPERIMENTAL RESULTS

In the following sections, the geotechnical and chemical properties of dredged soil are presented. The potential field of beneficial uses is proposed based on these properties. As shown in Table 1, grain size distribution, shear and compaction properties, heavy metal (Zn, Pb, Cu, Cd, Ni, and Ag) concentration, salinity, and other chemical properties (Al, Fe, Mg, SiO2 and Organic Content) are tested for the collected samples.

3.1 Chemical Properties of Dredged Sand

The study tested the use of dredged material for brick manufacturing using chemical parameters like Al, Fe, Mg, SiO2, and Organic Content in three soil samples. Results showed that the concentrations of these parameters were below the allowable limit for brick manufacturing, while the Silica content (75.2-77.2%) was found to be above the limit of 55%. The findings are presented in Table 2 and are supported by Baspinar et al. (2009) and Aziz (2012).

Table 2: Chemical Properties of Dredged Material

Chemical Parameter	**Sample ID**			**Allowable limit for brick (Aziz, 2012; Baspinar et al. 2009)**
	S-1	**S-2**	**S-3**	
Aluminum (Al)	1.2%	0.2%	0.8%	30%
Iron (Fe)	2.8%	4.0%	3.7%	8%
Magnesium (Mg)	0.1%	0.2%	0.4%	5%
Organic Matter	0.9%	1.8%	1.4%	1%
Silica (SiO2)	76.2%	75.2%	77.2%	55%

3.2 Concentration of Heavy Metals

The study examines the concentration of heavy metals in river bed sediment at the harbor area of Pussur River, comparing it with permissible limits set by various countries and international organizations. The concentrations of Zn, Pb, Cu, Cd, Ni, and Ag were found to be higher in dredged areas than in undredged areas. The top surface of the soil (undredged area) is generated from deposited sand, while the bottom layer remains unchanged. The permissible limit of heavy metals in soil varies based on its field of use. UK-GLC (1980) recommends a lower limit for land reclamation or reuse of material for filling purposes, while ICRCL, UK, and the World Health Organization have different limits for landfill cover and horticultural purposes. The test results (Table 3) show that the concentrations of Zn, Pb, Cu, Cd, and Ni in both dredged and undredged areas are well below the permissible limit. The study also highlights the potential contamination of silver by cement factories and coal-based power plants within 2 to 10 km upstream of the sample collection points. Kolesnikov (2020) reported an allowable value of 4.4 mg/kg for silver, while the measured concentration of Ag is very low compared to the allowable limit.

Table 3: Comparison of measured Heavy Metal concentration in river bed sediment at the harbor area of Pussur River with different permissible concentration limits

Heavy Metal Element	Measured Concentration (mg/kg)		Permissible Limit (mg/kg)				
	Dredged Area	Undredged Area	Italian legislation (Urban environ.)	EU regulation (plant-growing media)	UK-GLC (landfill cover/ Horticul.)	UK-GLC (for land reclamat./ filling)	World Health Organ. (WHO)
Zinc (Zn)	19.5	16.5	150	500	250	500	300
Lead (Pb)	7.5	5.4	100	120	500	1000	100
Copper (Cu)	19.1	14.6	120	200	100	--	30
Cadmium(Cd)	0.2	0.4	2.0	1.5	0.5	3	3
Nickel (Ni)	20.4	16.4	120	50	250	500	80
Silver (Ag)	<0.5	<0.5	--	--		--	--

In conclusion, the study highlights the importance of monitoring heavy metal concentrations in river bed sediment and their potential impact on human health.

3.3 Geotechnical Properties of Dredged Sand

3.3.1 Grain Size Analysis

The grain size distribution of dredged sand compared to Kustia and mixed sand is shown in Figure 2. The percentage passing through Sieve no. 200 varies from 4 to 9%, while Kustia and mixed sand contain 1 and 7% particles finer than 0.075 mm, respectively. Coarse-grained soil particles have grain sizes larger than 0.075 mm in engineering usage. Sand is used as a building material and foundation base. The Fineness Modulus of dredged material ranges from 0.58 to 0.72, meeting the minimum requirement of 0.50 set by the Public Works Department of Bangladesh for land development. Mixed sand has a FM of 0.84, while Kustia sand has a FM of 1.0. According to the Unified Soil Classification System (USCS), 91 to 96% of dredged soil samples have a particle size of 0.075 to 0.425 mm, classified as fine sand.

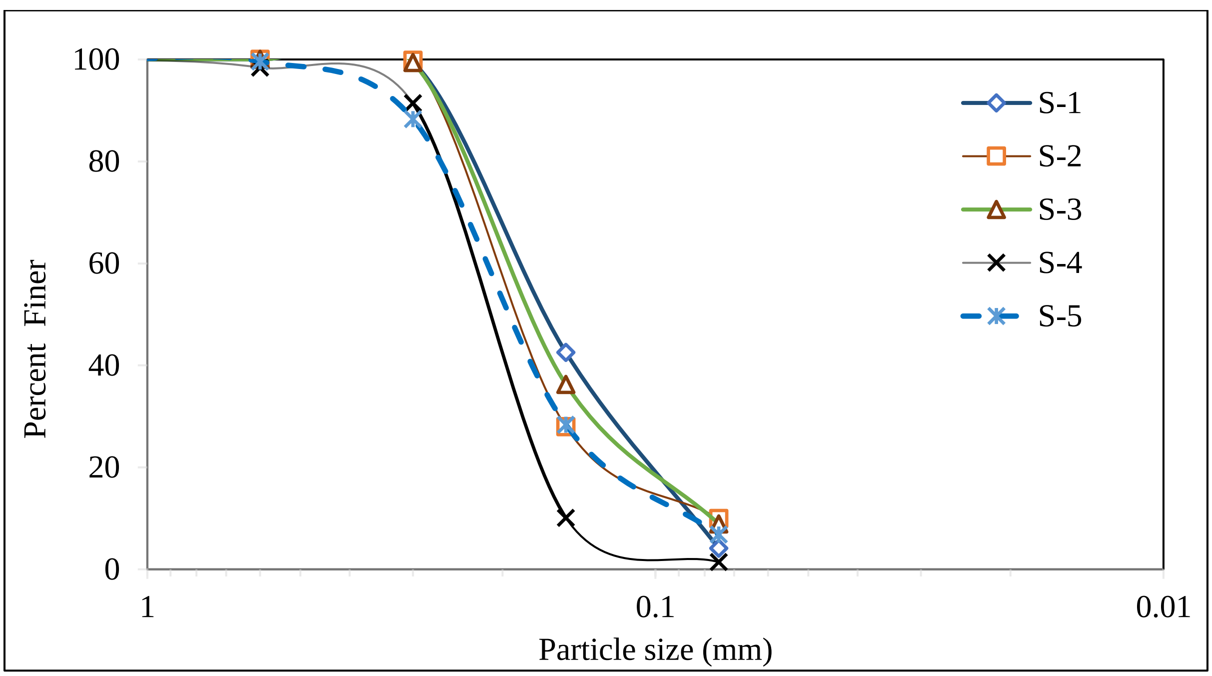

Figure 2: Grain size distribution curves of dredged sand samples

Table 4 presents the index properties of dredged sand which were obtained from particle size distribution analysis. These include the Fineness Modulus (FM), coefficient of uniformity (CU), and coefficient of Curvature (CC). For the dredged sand (S-1 to S-3), the CU values are found well above 2, which means that the samples are not uniform sand. The higher the value of CU the larger the range of particle sizes in the soil. According to USCS classification, all the soil samples fall under the SP group category and are poorly Graded Sand.

Table 4: Classification of Sand based on Uniformity and Gradation Coefficient (USCS)

Sample ID	% Passing No. 200 Sieve	Fineness Modulus FM	Coefficient of Uniformity CU	Coefficient of Curvature CC	Classification (USCS)	
					Group Symbol	**Group Name**
S-1	4.1	0.58	2.38	1.03	SP	Poorly Graded Sand
S-2	8.3	0.72	2.67	1.50	SP	
S-3	8.9	0.64	2.67	1.31	SP	
S-4	1.4	1.00	1.47	1.09	SP	
S-5	6.8	0.84	2.47	1.26	SP	

USCS: Unified Soil Classification System; SP: Poorly Graded Sand with little or no fines

Table 5: Suitability Rating for Pussur (dredged), Kustia, and mixed Sand

Sample ID	Fineness Modulus FM	D10 (mm)	D30 (mm)	D60 (mm)	Suitability Number, SN	Rating
S-1	0.58	0.08	0.125	0.19	32	Poor
S-2	0.72	0.075	0.15	0.2	30	Fair
S-3	0.64	0.075	0.14	0.2	33	Poor
S-4	1.00	0.15	0.19	0.22	20	Good
S-5	0.84	0.085	0.15	0.21	28	Fair

Table 5 shows the calculated Suitability Rating for Pussur, Kustia, and mixed Sands. It is observed that the suitability number for dredged sand varies from 30 to 33 which ranged from the rating of 'Poor to Fair'. The Kustia Sand has a significantly higher value of D10 compared to dredged sand and hence its SN value is low and scored a 'Good' rating. The mixed sand shows a 'Fair' rating.

3.3.2 Compaction and Shear Properties

Figure 3 shows the variation of dry density and moisture content in poorly graded fine sand, with maximum dry density ranging from 15.6 to 15.8 kN/m3 and optimal moisture content ranging from 16.3 to 17.7%. Direct Shear Strength tests were conducted on the dredged material, revealing an internal friction angle of 32^{o} to 34^{o}, which increased to 39^{o} to 42^{o} after compaction. The test results are shown in Table 6.

Table 6: Compaction (Standard Proctor) and Shear properties of dredged materials.

Sample	Optimum Moisture Content (%)	Maximum Dry Density (kN/m3)	Direct Shear Strength Parameters	
			Field sample	**Compacted**
S-1	17.2	1.56	C=5.8, ϕ = 32o	C=5.8, ϕ = 39o
S-2	16.3	1.58	C=8.9, ϕ = 34o	C=8.9, ϕ = 42o
S-3	17.7	1.56	C=6.4, ϕ = 33o	C=6.4, ϕ = 41o

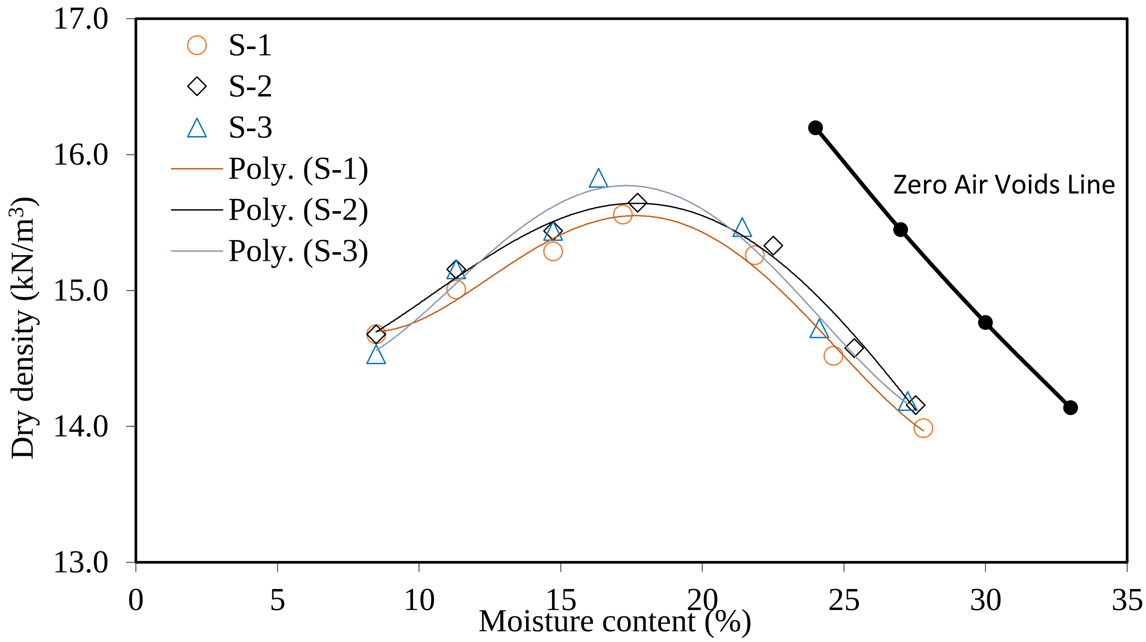

Figure 3: Compaction curve of dredged material.

4 CONCLUSION

The bed sediments collected from three disposal sites are mostly fine sand, with a Fineness Modulus ranging from 0.58 to 0.72. These soil samples fall under the SP group category and are poorly graded sand. The suitability number for dredged sand ranges from Poor to Fair, with Kustia Sand scoring a Good rating and mixed sand showing a fair rating. The angle of internal friction (ϕ) varies from 32 to 34^o, and the maximum dry density ranges from 15.6 to 16.8 kN/m3, with the optimum moisture content ranging from 16.3 to 17.7%.

The Pussur sediment has concentrations of Zn, Pb, Cu, Cd, and Ni well below the permissible limit, making it safe for land reclamation, landfill cover, horticultural purposes, or other geotechnical applications without further treatment. Brick manufacturing raw soils/clays must have plasticity, sufficient wet and air-dried strength, and fuse when subjected to appropriate temperatures. The chemical properties of dredged sediment indicate that the Al, Fe, Mg, and organic matter content is less than the allowable limit for brick clay, while silica exceeds the limit. Grain size analysis shows that the dredged material is mostly fine sand rather than clay, with a mean diameter of about 0.18 mm and less than 10% passing through a 0.075 mm sieve. Comparing the grain size and chemical properties with standard requirements, it can be concluded that this dredged material is not suitable for brick manufacturing.

Bangladeshi rivers' dredged sand, particularly Pussur River sand, has the potential to be exported to Singapore and the Maldives as filling material due to its grain size and quality, and the availability of an international navigable waterway for transportation, but requires further study on social and geopolitical issues. Based on the study results, sustainable management process of dredged material of Pussur River could be identified.

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