SEDIMENT CHARACTERISTICS TO SUPPORT THE REVITALIZATION OF TPPI TUBAN PORT, EAST JAVA, INDONESIA

KARAKTERISTIK SEDIMEN UNTUK MENDUKUNG REVITALISASI PELABUHAN TPPI TUBAN, JAWA TIMUR, INDONESIA

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ABSTRACT: TPPI Tuban Port is located in Tuban Regency, East Java. Geologically, the rocks are composed of reef limestone in the Paciran Formation, which is Pliocene–Early Pleistocene. The importance of complying with jetty capacity standards and water conditions in commercial ports is emphasized as the key to maintaining smooth port operations, making port revitalization a necessity. One of the main aspects to consider is the sedimentation problem, closely related to sediment characteristics. A deep understanding of sediment dynamics is essential for designing effective solutions to ensure the sustainability of port operations. This research aims to determine the distribution pattern of bed load characteristics such as water content, specific gravity, gradation, sediment texture, d50 size of sediment grains, and statistical analysis of bed load sediment in the west and rainy seasons, where the influence of sediment from land is very large. so it is hoped that it can support the port revitalization plan. The methods used include taking sediment samples in the field, testing sediment samples in the laboratory, statistical sediment analysis, and descriptive analysis of bed load characteristics using the Gradistat method. Based on the study results, the water content value ranges from 22.446% to 218.289%, and the specific gravity ranges from 2,100 g/m³ to 2.690 g/cm³. Additionally, the grain size varies from 0.080 mm to 0.900 mm, and the average grain size ranges from 261.1 µm to 2657.5 µm. Sediment sorting is dominated by very poorly sorted materials, with statistical analysis indicating a dominance of the very platykurtic type. The lithological type is predominantly sand.

Keywords: bed load, statistics, sediment texture, Tuban, East Java

ABSTRAK: Pelabuhan TPPI Tuban terletak di Kabupaten Tuban, Jawa Timur. Secara geologi batuannya tersusun oleh batugamping trumbu pada Formasi Paciran yang berumur Pliosen-Pleistosen Awal. Pentingnya mematuhi standar kapasitas jetty dan kondisi perairan dalam pelabuhan niaga ditekankan sebagai kunci untuk menjaga kelancaran operasional pelabuhan ,oleh karena itu, revitalisasi pelabuhan dianggap suatu keharusan. Salah satu aspek utama yang perlu diperhatikan adalah permasalahan sedimentasi, yang sangat terkait dengan karakteristik sedimen itu sendiri. Pemahaman mendalam terhadap dinamika sedimen menjadi esensial untuk merancang solusi yang efektif dalam mengatasi masalah ini dan memastikan keberlanjutan operasional pelabuhan. Tujuan penelitian ini adalah untuk mengetahui pola sebaran karakteristik sedimen dasar seperti kadar air, berat jenis, gradasi, tekstur sedimen, ukuran d50 butir sedimen dan analisis statistik sedimen dasar laut pada musim barat/musim hujan mendukung rencana revitalisasi pelabuhan. Metode yang dipakai adalah pengambilan sampel sedimen di lapangan, pengujian sampel sedimen di laboratorium, analisis sedimen secara statistic dan analisis deskriptif karakteristik sedimen dasar menggunakan metode Gradistat. Berdasarkan hasil kajian diketahui nilai kadar air 22,446 % - 218,289 %, berat jenis 2,100 g/m3 – 2,690 g/cm3, ukuran butir 0,080 mm – 0,900 mm, ukuran rerata butir 261,1 µm - 2657,5 µm, sortasi sedimen didominasi very poorly sorted (terpilah sangat buruk), analisis statistik sedimen didominasi tipe very platykurtic, jenis lithologi didominasi oleh pasir.

Kata Kunci: sedimen dasar, statistik, tekstur sedimen, Tuban, Jawa Timur

INTRODUCTION

Shipping stands as a cornerstone of transportation in Indonesia, particularly given its status as a maritime nation with expansive seas. Beyond serving public transportation needs, shipping plays a crucial role in facilitating trade activities, notably in sectors such as coal, oil, and gas. This assertion aligns with the findings by Saepuloh et al. (2017), who delineate shipping into two categories: commercial and non-commercial. Commercial shipping, as highlighted in their study, handles the bulk of imported and exported goods, along with large cargo volumes. Additionally, ensuring seamless shipping operations entails addressing various infrastructure needs, including robust port facilities.

As described by Notteboom et al. (2022) a port serves as a pivotal transit area and gateway facilitating the movement of goods and people to and from the sea. In Indonesia, ports are not solely under governmental ownership but also have partnerships with various companies, particularly those involved in the oil and gas processing sector. Ports owned by these partner entities primarily facilitate the transportation of raw materials to or from industrial sites. For instance, PT Trans-Pacific Petrochemical Indotama (TPPI) operates a port for such purposes.

To ensure the capacity and seamless operations of companies, commercial ports must adhere to specific standards, particularly concerning jetty capacity and water conditions such as currents and waves. Business Continuity Management (BCM) becomes imperative in maintaining operational continuity and safeguarding against disruptions that could potentially halt business operations, particularly in critical sectors like ports (Budiyanto, 2022). This necessity underscores the importance of port rejuvenation or revitalization efforts.

In the planning of port revitalization, a crucial aspect that requires study is the sedimentation process. All marine structures inherently disturb the balance of sediment transport along the shoreline (longshore current), potentially resulting in alterations to sediment supply, so that these marine structures can either diminish, halt, or augment sediment supply (Diposaptono, 2011; Melisa et al., 2020).

The sedimentation process in ports is intricately linked to dredging activities during the operational stage, as dredging significantly impacts a port's competitiveness. Dredging can enhance port efficiency by 3-10%, reduce port costs by 1-24%, and increase port operator income by 3-19% (Rosyidi, 2015). For instance, the annual cost of dredging to mitigate silting at Baai-Bengkulu Island Harbor amounts to Rp. 28-30 billion (Supiyati et al., 2011). The sedimentation rate at Pulau Baai Harbor parallels the construction pace of a 390-meter-long breakwater from the beach. Despite the design expectation of reaching a distance of 400 meters after 10 years, in reality, sand deposits reached the end of the breakwater within just 3 years (Hamdani, 2013). Combining sediment management and (bio) remediation in ports has the potential to reduce dredging need and remediate contaminated mud, potentially improving port competitiveness (Polrot et al., 2021).

Understanding underwater conditions, especially seabed sediment, is crucial in planning the revitalization of coastal structures (Pasaribu et al., 2021; Permana et al., 2012; Siry, 1990). Sediment transport along coastlines leads to various issues such as shallowing and beach erosion, underscoring the significance of studying sediment transport predictions (Triatmodjo, 1999; Umar et al., 2020). Sediment transport around coastal areas encompasses both onshore-offshore and longshore transport (Triatmodjo, 1999; Thunyaphun et al., 2023). Tidal fluctuations, a primary cause of current patterns and sediment movement in sheltered coastal regions, significantly influence sediment transport, particularly in estuaries, bay mouths, or protected straits (Wahyudi and Jupantara, 2004; Ali et al., 2017; Pu et al, 2022). Tidal currents not only affect wave height, which carries sediment to and from the coast, but also impact current speed and direction, facilitating substantial sediment transport (Wahyudi and Jupantara, 2004; Ali et al., 2017; Pu et al, 2022). In contrast, for open beaches, wave energy plays a significant role alongside tidal currents in the sedimentation process (Purba et al., 2022). According to (Rifardi, 2012), the most dominant factors influencing sedimentation are currents and waves (Ansari et al., 2020; Dwinanto et al., 2017).

Tides and river estuary discharge are among the key factors influencing sediment distribution (Andayani et al., 2020; Dwianti et al., 2017). Understanding the distribution of sediment fractions is crucial for analyzing the shallowing process. Factors such as distribution, cohesiveness, density, and grain size play dominant roles in sediment transport (Rachman and Wibowo, 2019). Sediment characteristics, including grain size, sediment type, and classification parameters, along with sediment distribution, are significant marine dynamic factors influencing sediment deposition and defining the sedimentation environment (Liu et al., 2023; Rifardi, 2008). The distribution and heterogeneity of sediment gradation serve as indicators of sediment flow behavior in an area (Anggraini et al., 2020; Junaidi and Wigati, 2011; Nugroho and Basit, 2014; Rachman et al., 2021).

Sedimentation in seawater results not only from the deposition of suspended sediment material but also from the movement of bed load in the area. The settling speed of cohesive sediment is influenced by various factors including the concentration of suspended sediment, salinity, and the diameter of underlying sediment particles (Rachman and Wibowo, 2022). An alternative method for studying sedimentation environments and determining sediment transport direction involves determining statistical parameters such as mean grain size, standard deviation, skewness, and kurtosis, which are commonly utilized (Affandi and Surbakti, 2012; Muhardi et al., 2022). This study aims to ascertain the distribution pattern of seabed sediment characteristics during the west season, particularly significant due to the substantial influence of sediment from land during this period. These characteristics are pivotal for further sedimentation studies, serving as crucial input data for both analytical and numerical modeling of sedimentation velocity. Additionally, they are integral for numerical studies regarding the revitalization of the TPPI Tuban port.

The research is conducted in the waters surrounding TPPI Tuban Port, East Java, where a port has been established. Thus far, there has been limited research conducted on sedimentation and sediment characteristics at this location. Therefore, as an initial investigation, this study focuses on examining the characteristics of the bed load.

To analyze the characteristics of bed loads, the Gradistat statistical method will be employed. This method, proposed by (Blott, 2010; Blott and Pye 2001) in collaboration with *Kenneth Pye Associates Ltd*., operates within the Microsoft Excel program. The calculation methods utilized include the *Method of Moments* (mathematical) and the *Folk and Ward* approach (graphical). Gradistat serves as an alternative to computational numerical modeling software for sediment analysis. One of its key advantages is its accessibility and cost-effectiveness, as it does not require licensing fees and can be easily implemented, leveraging the familiarity of Microsoft Excel.

METHODS

The research implementation comprises several stages: (1) Field sampling of bed load. (2) Laboratory analysis of soil water content in bed loads, utilizing the SNI 1965:2019 method, which follows the Test Method for Determining Water Content for Soil and Rock (BSN, 2019). (3) Determination of soil specific gravity in bed load, employing the SNI 1964:2008 method for testing soil specific gravity (BSN, 2008a). (4) Analysis of soil gradation in bed loads, utilizing the SNI 3423:2008 method for testing soil grain size analysis (BSN, 2008b). (5) Analysis of sediment characteristics using the Gradistat method.

Sediment sampling employs tools such as a sediment grabber, plastic sampler, and permanent marker. Soil mechanics testing involves the use of various equipment, including scales, ceramic cups, pycnometers, measuring cups, measuring tubes, desiccators (cooling devices), ovens, thermometers, hydrometers, electric furnaces, porcelain cups, suspension stirrers, stopwatches, and sieve shakers. Additionally, distilled water and reagent fluids are utilized as materials for soil mechanics testing.

Sediment sampling was conducted using a purposive sampling method, covering the waters surrounding TPPI Tuban. In July 2020, a total of 30 samples were collected (refer to Figure 1 and Table 1) for subsequent laboratory testing, which took place in August 2020.

The analysis of the distribution characteristics of seabed sediment in the waters of TPPI Tuban employs the Gradistat version 8 method. This analysis focuses on discussing statistical grain size distribution for unconsolidated soil types, utilizing sieving and laser granulometer methods (Blott, 2010; Blott and Pye 2001). The aim is to provide a descriptive and systematic account of the bed load

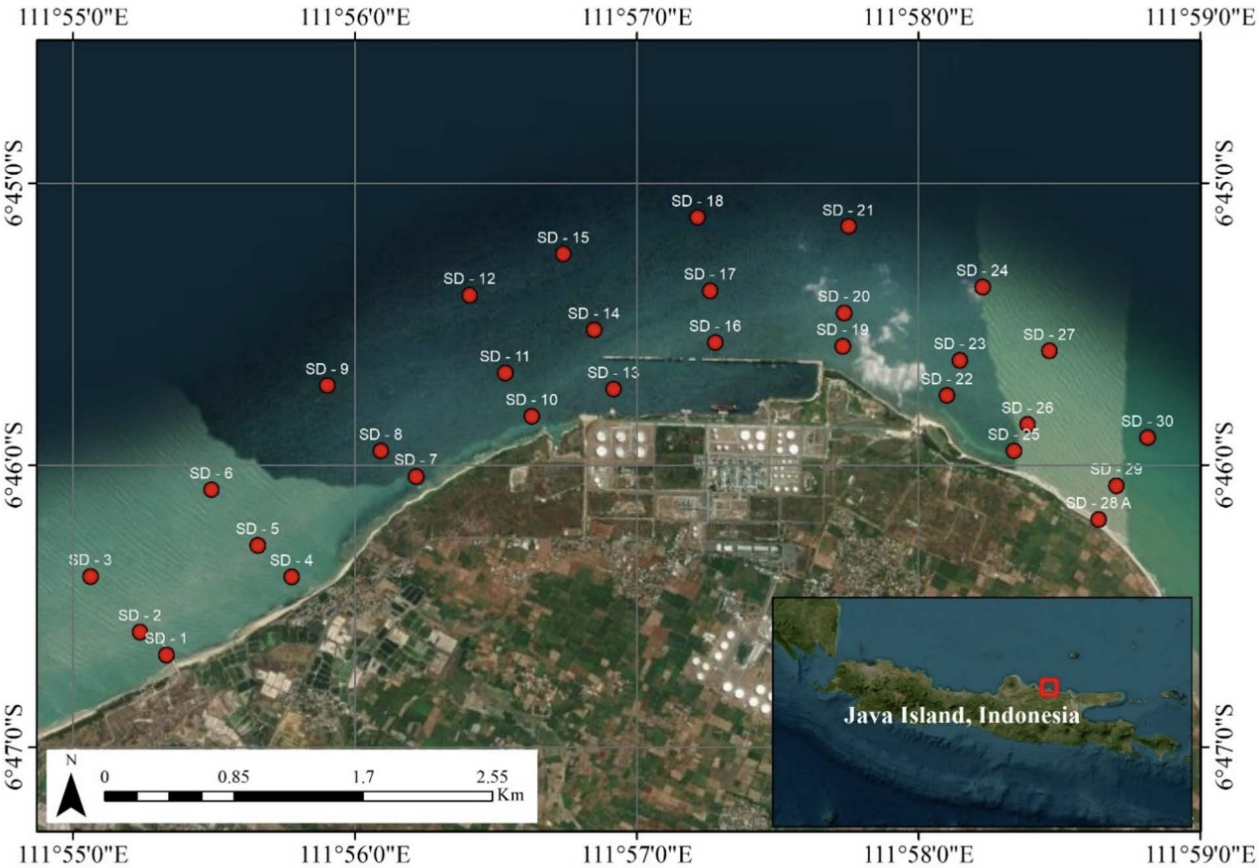

Figure 1. Bed load sampling location

Table 1. Bed load sampling coordinate point (converted to UTM zone 49S)

No	Code	Depth (m)	Date	Time (WIB)	X	Y
1	SD - 1	2	09/07/2020	9:51	601906.695	9250707.637
2	SD - 2	4.5	09/07/2020	9:58	601735.72	9250857.686
3	SD - 3	5	09/07/2020	10:05	601412.357	9251222.999
4	SD - 4	3	09/07/2020	9:04	602727.634	9251218.114
5	SD - 5	3	09/07/2020	9:36	602506.428	9251423.533
6	SD - 6	5	09/07/2020	9:29	602204.507	9251786.426
7	SD - 7	3	09/07/2020	9:10	603541.419	9251872.062
8	SD - 8	6	09/07/2020	9:15	603312.992	9252039.359
9	SD - 9	5	09/07/2020	9:21	602963.538	9252466.708
10	SD - 10	3	09/07/2020	9:00	604299.911	9252263.903
11	SD – 11	5	09/07/2020	8:57	604126.515	9252547.897
12	SD – 12	6	09/07/2020	8:49	603893.979	9253056.07
13	SD – 13	7	08/07/2020	10:15	604834.053	9252438.394
14	SD – 14	5	09/07/2020	8:35	604706.085	9252825.663
15	SD – 15	7	08/07/2020	8:41	604506.894	9253324.24
16	SD – 16	5	08/07/2020	10:46	605499.414	9252743.067
17	SD – 17	5.5	08/07/2020	10:51	605466.717	9253081.615
18	SD – 18	7	08/07/2020	10:57	605384.255	9253560.898
19	SD – 19	4	08/07/2020	10:39	606330.98	9252717.593
20	SD – 20	5	08/07/2020	10:35	606340.94	9252934.49
21	SD – 21	5	08/07/2020	10:28	606370.651	9253499.366
22	SD – 22	5.5	08/07/2020	9:39	607011.835	9252394.443
23	SD – 23	6.5	08/07/2020	9:38	607098.072	9252623.107
24	SD – 24	8.5	08/07/2020	9:42	607246.764	9253101.934
25	SD – 25	5	08/07/2020	12:22	607449.553	9252031.248
26	SD – 26	5.7	08/07/2020	9:28	607538.065	9252205.081
27	SD – 27	7.5	08/07/2020	9:22	607681.995	9252683.917
28	SD – 28	3	08/07/2020	11:59	608001.467	9251582.005
29	SD – 29	4	08/07/2020	9:18	608118.666	9251801.07
30	SD – 30	5	08/07/2020	9:15	608321.84	9252115.31

characteristics, ensuring a factual and accurate portrayal of the observed phenomena and their interrelationships ((Nazir, 1983; Rachman and Wibowo, 2019). Understanding the statistics of bedload particle motions is of great importance (Zi et al., 2023)

RESULTS AND DISCUSSIONS

Based on the results of analyses conducted at the Geotechnical and Soil Mechanics Laboratory, BTIPDP-BPPT, the distribution patterns and the characteristics of bed load sediments such as water content, specific gravity, gradation, sediment texture, d50 size of sediment grains, and statistical analysis of seabed sediments in the waters of TPPI Tuban are as follows:

Soil Water Content

Soil water content represents the comparison between the mass (weight) of water or wet content within the soil and the dry mass (weight) of the soil, typically expressed as a percentage (BPPT, 2021). The soil's capacity to retain water can be measured by weight or volume. Factors like temperature and humidity impact the lower limits of water content and matric potential in soil, affecting its ability to retain water (Tianyu et al., 2022). In addition to soil properties, climate factors significantly impact the soil's water retention capability, including temperature, humidity, and wind speed (Salam, 2020). Soil texture plays a crucial role in determining water-holding capacity, with coarse-textured soils generally having lower capacity compared to fine-textured soils. Consequently, silt soils tend to retain moisture more effectively than sandy soils (Salam, 2020; Caroline et al., 2023; Chunliu et al., 2023).

The soil water content in the research area varies from 22.446% to 218.289% (refer to Table 2). The highest water content, recorded at 218.289%, is observed at point SD-13 within the anchor pool of TPPI Tuban, while the lowest, at 22.446%, is found at point SD-1 in the waters off Pier Beach, west of TPPI Tuban.

Soil Specific Gravity

The specific gravity of sedimentary soil represents the ratio of sediment particle size to the volume weight of water (Ponce, 1989; Rashid et al., 2017; Mira, 2021). Specific gravity is necessary for computing the soil's void ratio and determining the grain-size distribution in hydrometer analysis (Mir, 2021). Generally, sediment has a specific gravity estimated at around 2.65 g/cm3, unless it contains heavy materials like magnetite, in which case the specific gravity can reach around 5.18 g/cm3 (Hambali and Apriyanti, 2016). In the study area, the specific gravity of bed loads ranges from 2.1 g/cm3 to 2.69 g/cm3 (refer to Table 3). These sediments are classified as light, likely due to their composition containing silicate minerals (SiO_2) and a significant amount of organic minerals such as peat or humus, which have low specific gravity (Hardiyatmo, 2002; Volkov et al., 2021). The distribution pattern of sediment specific gravity appears consistent, although sediment with the lowest specific gravity is found north of the Tuban TPPI breakwater (SD-17) at 2.1 g/cm3, while the highest is in the waters of Sumur Pawon Beach (SD-25) at 2.69 g/cm3. This variation is attributed to the dominant influence of sediment rich in humus/peat during sampling.

Table 2. Bed load water content

Sample Code	**SD-1**	**SD-2**	**SD-3**	**SD-4**	**SD-5**	**SD-6**	**SD-7**	**SD-8**	**SD-9**	**SD-10**
Water Content (%)	22.446	50.259	50.30	24.355	37.32	205.946	34.192	34.20	39.1	39.942
Sample Code	**SD-11**	**SD-12**	**SD-13**	**SD-14**	**SD-15**	**SD-16**	**SD-17**	**SD-18**	**SD-19**	**SD-20**
Water Content (%)	205.061	176.482	218.289	212.911	213.1	213.866	190.17	169.335	168.219	155.465
Sample Code	**SD-21**	**SD-22**	**SD-23**	**SD-24**	**SD-25**	**SD-26**	**SD-27**	**SD-28**	**SD-29**	**SD-30**
Water Content (%)	171.746	168.444	128.065	108.218	59.06	69.434	130.553	112.657	104.312	136.536

Table 3. Bed load specific gravity

Sample Code	SD-1	SD-2	SD-3	SD-4	SD-5	SD-6	SD-7	SD-8	SD-9	SD-10
Specific Gravity (g/cm^3)	2.439	2.524	2.53	2.657	2.621	2.200	2.542	2.55	2.3	2.299
Sample Code	**SD-11**	**SD-12**	**SD-13**	**SD-14**	**SD-15**	**SD-16**	**SD-17**	**SD-18**	**SD-19**	**SD-20**
Specific Gravity (g/cm^3)	2.164	2.371	2.267	2.355	2.4	2.470	2.100	2.347	2.309	2.28
Sample Code	**SD-21**	**SD-22**	**SD-23**	**SD-24**	**SD-25**	**SD-26**	**SD-27**	**SD-28**	**SD-29**	**SD-30**
Specific Gravity (g/cm^3)	2.414	2.473	2.512	2.455	2.690	2.529	2.675	2.669	2.501	2.439

Gradation and Sediment Texture

Grain size analysis is a method used to determine the distribution of soil grain sizes, specifically for soil samples without grains larger than 2 mm. The analysis involves sediment examination with a hydrometer for particles smaller than sieve no. 10 (0.0075 mm), while particles retained on sieve no. 200 (0.0075 mm) are analyzed using a sieve (BPPT, 2021).

According to the d50 value of the grain size (refer to Table 4), the majority of seabed sediments in the study area are classified as very fine sand (12 samples), fine sand (7 samples), medium sand (1 sample), and silt (10 samples).

The level of sediment grain gradation, indicating variations in grain size, is determined by the d90/d10 value, where a higher d90/d10 value signifies better sediment gradation or more diverse grain sizes. In the study area, all seabed sediments are classified as well-graded, as their d90/d10 values are below 3 (Hardiyatmo, 2002) (refer to Table 5).

The analysis of sediment grain size reveals that the lithology of the majority of seabed sediment in the study area consists mainly of sand with a minor presence of silt (refer to Figures 3 and 4, and Table 4). Sand fraction dominates the sediment, ranging from 11.8% to 92.2%, followed by the mud fraction ranging from 0.3% to 25.2%, and the gravel fraction ranging from 7.5% to 77.3% (refer to Table 6). These findings align with previous research conducted in areas surrounding the study location, which indicated that the bed load in Tuban TPPI waters is predominantly composed of sand with a d50 size ranging from 0.09 to 0.35 mm (Wibowo, 2018). This sand dominance is likely attributed to the presence of small currents in areas with finer-grained bed loads. Such currents tend to transport fine sediment particles over distances, resulting in their deposition in locations farther from the source (Rifardi, 2008; Mengual at al, 2020). The consistency between the results of this study and previous research underscores the reliability of the findings.

Specifically, the sand fraction is primarily composed of very fine sand. Detailed composition and percentage data of gravel, sand, silt, and mud from each sediment sample are provided in Table 6, Figure 2, Figure 3, and Figure 4.

Table 4. D50 Bed load

Sample Code	SD-1	SD-2	SD-3	SD-4	SD-5	SD-6	SD-7	SD-8	SD-9	SD-10
D50 (mm)	0.140	0.095	0.095	0.140	0.140	0.350	0.089	0.089	0.090	0.090
Sample Code	**SD-11**	**SD-12**	**SD-13**	**SD-14**	**SD-15**	**SD-16**	**SD-17**	**SD-18**	**SD-19**	**SD-20**
D50 (mm)	0.140	0.100	0.150	0.095	0.095	0.100	0.150	0.330	0.210	0.100
Sample	**SD-21**	**SD-22**	**SD-23**	**SD-24**	**SD-25**	**SD-26**	**SD-27**	**SD-28**	**SD-29**	**SD-30**
D50 (mm)	0.290	0.140	0.400	0.100	0.900	0.250	0.500	0.080	0.090	0.350

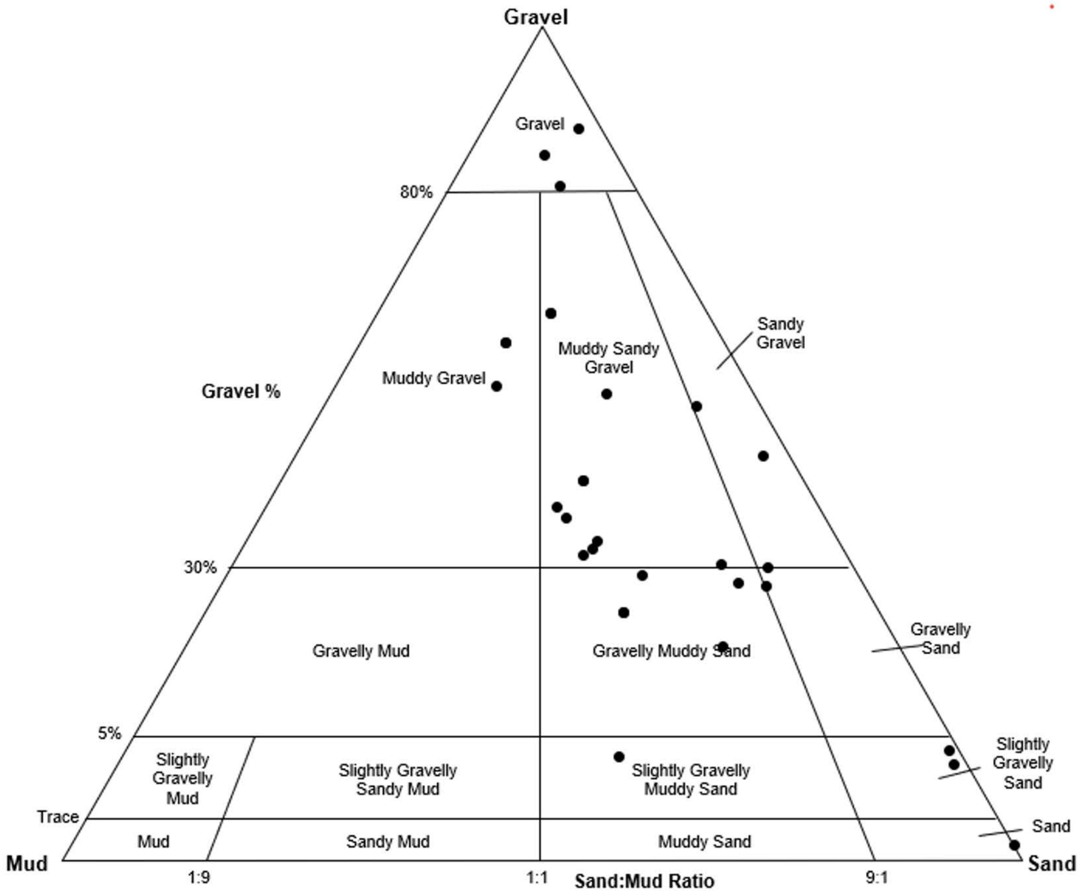

Figure 2. Sediment grain size classification based on sheppard's triangle (1954)

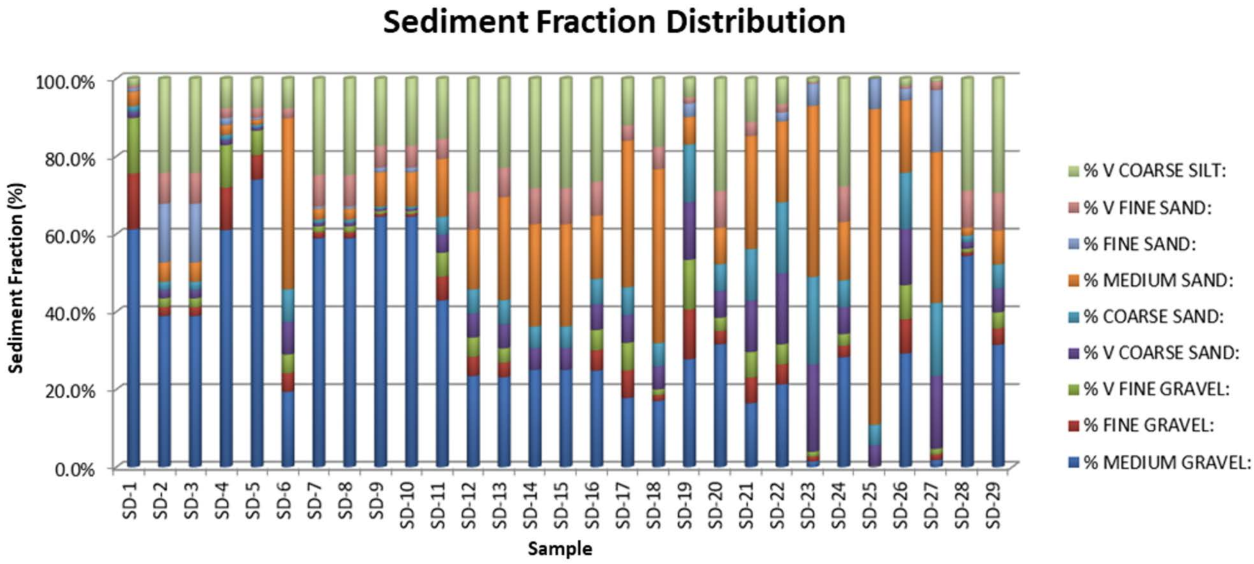

Figure 3. Bed load fraction distribution graph

Statistical Analysis of Sediment Grains

Statistical analysis serves to describe the frequency distribution of grain sizes, typically expressed through four parameters: mean, sorting, skewness, and kurtosis. The mean represents the arithmetic average of various grain sizes within a sediment sample. Sorting, indicated by the standard deviation, illustrates the width of the distribution around the mean. Skewness measures the asymmetry of the distribution, while kurtosis indicates the peak or flatness compared to a normal distribution (Dyer, 1996; Oyedotun, 2022). The equations and methods employed for statistical analysis of sediment grains and classification in this research follow the Folk and Ward Method (Blott, 2010; Blott and Pye, 2001; Folk and Ward, 1957; Raj and Nilanjana, 2021). The results of the statistical values of sediment grain size measurement are presented in Table 5.

Average Sediment Grain Size (Mean)

The average grain size serves as an index to measure grain size distribution within a sample, representing the weighted percentage of each fraction. This value is indicative of the predominant grain size within the sample and can provide insights into the energy dynamics driven by water flow or wind in the area (Folk and Ward, 1957; Friedman, 1967; Sakai and Hotta, 2023).

The average grain size of sediments in the study area ranges from 261.1 µm to 2657.5 µm, categorizing the sediment as very fine sand (refer to Table 6). The presence of sand-sized bed loads indicates strong currents capable of forming sand sediment deposits in the area (Nybakken, 1992; Phillipe et al., 2022) Similarly, (Rifardi, 2012) notes that dominance of coarse sediment grains suggests significant flow strength anchoring the sediment, while dominance of fine/small sediment indicates weaker flow energy responsible for sediment transport.

Sediment Grain Sorting

Sorting is an indicator of sediment grain uniformity, reflects the level of uniformity of sediment grains (Rachman et al., 2021). A smaller sorting value indicates better sorting, resulting in more uniform sediment grain sizes, whereas a larger sorting value suggests poorer sorting and less uniform grain sizes (Rifardi, 2012; Blott, 2010; Blott and Pye, 2001; Campmans & Wijnberg, 2022). Sorting provides insights into particle size limits, sediment type, flow characteristics, and sediment transport duration from the sediment source. In the research area, sorting varies from moderately sorted (1 sample) to very poorly sorted (23 samples). Well-sorted sediment grains indicate a stable current environment with relatively uniform grain size deposition, while poorly sorted grains suggest an unstable current environment with varying grain sizes. This variability implies fluctuations in current strength, with periods of strong currents followed by weaker currents under different conditions.

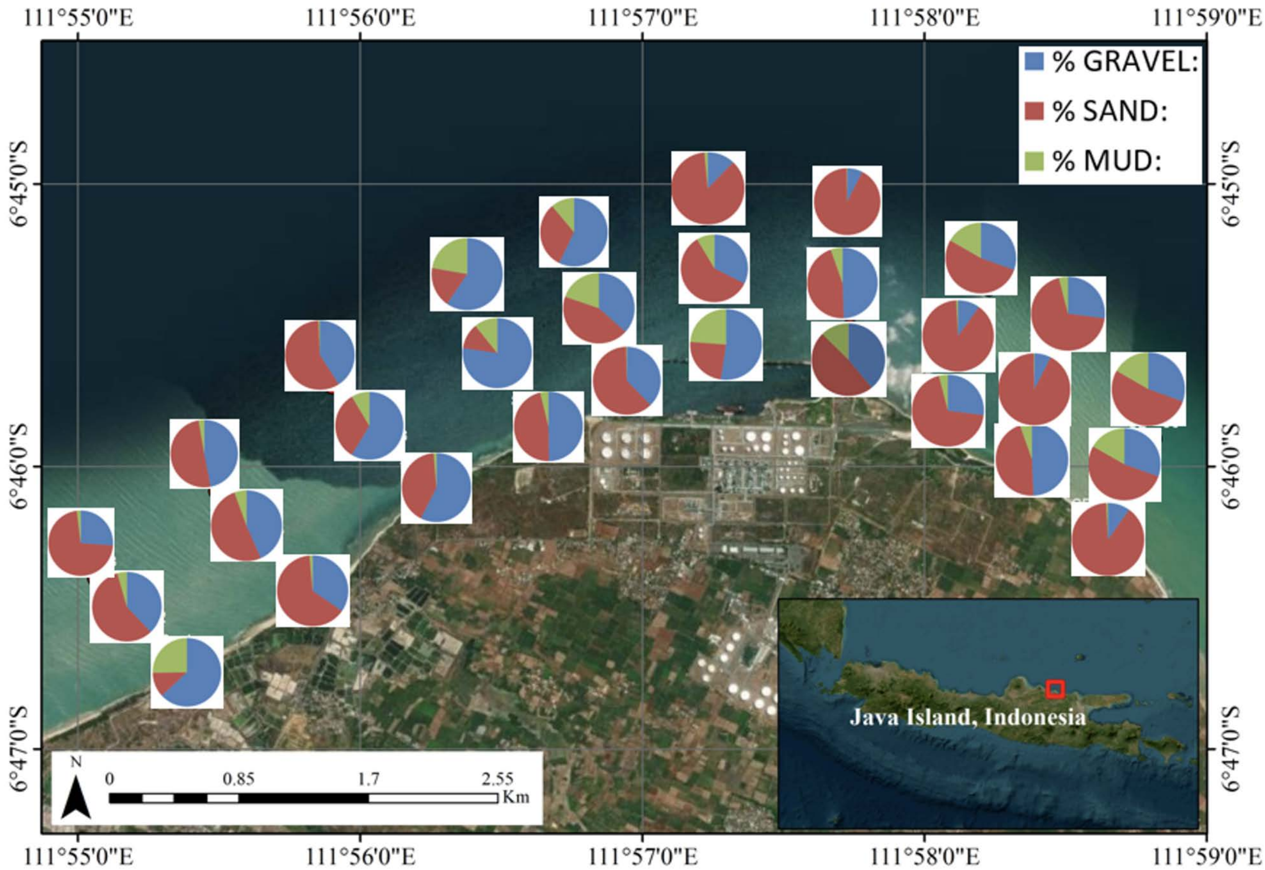

Figure 4. Distribution map of bed load fractions at each sampling location

Based on the sorting analysis of sediment grains in the research area, they are classified as moderately well sorted at 2 locations, moderately sorted at 1 location, poorly sorted at 4 locations, and predominantly very poorly sorted at 23 locations (refer to Table 6). This indicates stable current strength in the waters, with consistent conditions of stable currents that do not fluctuate over time. This stability may be influenced by river discharge entering the sea waters around the research area.

Dominance of Sediment Grain Size (Skewness)

The skewness characterizes the predominant direction of grain size distribution within a population, indicating whether it leans towards coarse-grained or fine-grained sediment, or exhibits symmetry (Rifardi, 2008; Khalil, 2023). A positive skewness value suggests a tendency towards fine grained sediment, while a negative skewness value indicates a tendency towards coarse-grained sediment. Skewness is influenced by wave and current characteristics, making it a valuable indicator of their strength in the deposition process. Based on statistical analysis results, the bed load in the study area predominantly exhibits positive skewness, with 21 out of 30 samples showing positive values, while only 9 samples exhibit negative values (refer to Table 6). Positive values indicate fine skewed to very fine skewed or symmetrical distributions, while negative values indicate very coarse skewed to coarse skewed distributions. This suggests that the aquatic environment in the study area is characterized by a predominance of fine-grained sediment and relatively weak currents.

Sediment Grain Size Distribution (Kurtosis)

The kurtosis measures the peak of the distribution curve and is indicative of the spread of the normal distribution (Rifardi, 2008; Perera et.al., 2023). A mesokurtic distribution curve is moderately peaked, neither too sharp nor too flat. A leptokurtic curve is sharply peaked, indicating a dominant sediment size in the distribution, while a platykurtic curve is flat, suggesting uniform sediment size distribution. Based on statistical analysis results, nearly all bed load samples in the study area exhibit very platykurtic distribution (24 samples) (refer to Table 6). This indicates dominance of a specific sediment grain size, namely very fine sand sediment, in the study area.

Table 5. Results of bed load texture analysis

	SD-1	**SD-2**	**SD-3**	**SD-4**	**SD-5**	**SD-6**	**SD-7**	**SD-8**	**SD-9**	**SD-10**
TEXTURAL GROUP:	Gravel	Muddy Sandy Gravel	Muddy Sandy Gravel	Gravel	Gravel	Gravelly Muddy Sand	Muddy Gravel	Muddy Gravel	Muddy Gravel	Muddy Gravel
(d90 / d10):	0.200	-0.669	-0.669	-0.742	-0.570	-1.067	-0.391	-0.391	-0.296	-0.296

	SD-11	**SD-12**	**SD-13**	**SD-14**	**SD-15**	**SD-16**	**SD-17**	**SD-18**	**SD-19**	**SD-20**
TEXTURAL GROUP:	Muddy Sandy Gravel	Muddy Sandy Gravel	Muddy Sandy Gravel	Gravelly Muddy Sand	Gravelly Muddy Sand	Muddy Sandy Gravel	Muddy Sandy Gravel	Gravelly Muddy Sand	Muddy Sandy Gravel	Muddy Sandy Gravel
(d90 / d10):	-0.946	-1.058	-1.168	-0.877	-0.877	-1.030	-1.068	-1.231	-0.545	-0.998

	SD-21	**SD-22**	**SD-23**	**SD-24**	**SD-25**	**SD-26**	**SD-27**	**SD-28**	**SD-29**	**SD-30**
TEXTURAL GROUP:	Gravelly Muddy Sand	Sandy Gravel	Slightly Gravelly Sand	Muddy Sandy Gravel	Slightly Gravelly Sand	Sandy Gravel	Slightly Gravelly Sand	Muddy Gravel	Muddy Sandy Gravel	Slightly Gravelly Muddy Sand
(d90 / d10):	-1.189	-0.638	-2.656	-0.906	2.383	-0.503	-3.369	-0.147	-0.841	3.613

Table 6. Results of statistical analysis of sediment granules

Sample Code		SD-1	SD-2	SD-3	SD-4	SD-5	SD-6	SD-7	SD-8	SD-9	SD-10
FOLK AND WARD METHOD (Description)	MEAN:	5409.4	434.0	434.0	4091.8	4706.2	1035.9	1161.6	1161.6	1196.7	1196.7
	SORTING:	1.573	5.363	5.363	2.601	1.777	5.433	4.651	4.651	4.155	4.155
	SKEWNESS:	-2.738	-0.003	-0.003	-1.809	-5.931	0.481	-1.917	-1.917	-2.145	-2.145
	KURTOSIS:	0.618	0.294	0.294	1.087	-75.655	0.864	0.330	0.330	0.539	0.539
FOLK AND WARD METHOD (Description)	MEAN:	Fine Gravel	Medium Sand	Medium Sand	Fine Gravel	Fine Gravel	Very Coarse Sand	Very Coarse Sand	Very Coarse Sand	Very Coarse Sand	Very Coarse Sand
	SORTING:	Moderately Well Sorted	Very Poorly Sorted	Very Poorly Sorted	Poorly Sorted	Moderately Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted
	SKEWNESS:	Very Fine Skewed	Symmetrical	Symmetrical	Very Fine Skewed	Very Fine Skewed	Very Coarse Skewed	Very Fine Skewed	Very Fine Skewed	Very Fine Skewed	Very Fine Skewed
	KURTOSIS:	Very Platykurtic	Very Platykurtic	Very Platykurtic	Mesokurtic	Very Platykurtic	Platykurtic	Very Platykurtic	Very Platykurtic	Very Platykurtic	Very Platykurtic
Percentage	Gravel	89.9%	43.4%	43.4%	82.9%	86.6%	29.0%	62.0%	62.0%	65.9%	65.9%
	Sand	8.3%	32.3%	32.3%	9.5%	5.8%	63.3%	13.3%	13.3%	16.8%	16.8%
	Mud	1.9%	24.2%	24.2%	7.6%	7.6%	7.7%	24.8%	24.8%	17.3%	17.3%

Sample Code		SD-11	SD-12	SD-13	SD-14	SD-15	SD-16	SD-17	SD-18	SD-19	SD-20
FOLK AND WARD METHOD (Description)	MEAN:	1341.0	603.4	606.8	519.7	519.7	638.1	665.4	585.1	2332.7	726.8
	SORTING:	6.471	7.394	7.370	6.596	6.596	7.327	6.298	7.706	4.213	7.401
	SKEWNESS:	-0.928	0.078	0.120	0.096	0.096	0.032	0.116	0.239	-0.355	-0.140
	KURTOSIS:	0.434	0.360	0.400	0.454	0.454	0.344	0.647	1.407	0.693	0.319
FOLK AND WARD METHOD (Description)	MEAN:	Very Coarse Sand	Coarse Sand	Coarse Sand	Coarse Sand	Coarse Sand	Coarse Sand	Coarse Sand	Coarse Sand	Very Fine Gravel	Coarse Sand
	SORTING:	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted
	SKEWNESS:	Very Fine Skewed	Symmetrical	Coarse Skewed	Symmetrical	Symmetrical	Symmetrical	Coarse Skewed	Coarse Skewed	Very Fine Skewed	Fine Skewed
	KURTOSIS:	Very Platykurtic	Very Platykurtic	Very Platykurtic	Very Platykurtic	Very Platykurtic	Very Platykurtic	Very Platykurtic	Leptokurtic	Platykurtic	Very Platykurtic
Percentage	Gravel	55.2%	33.3%	30.6%	25.0%	25.0%	35.3%	32.0%	20.0%	53.4%	38.5%
	Sand	29.3%	37.4%	46.5%	46.8%	46.8%	38.2%	56.0%	62.5%	41.8%	32.6%
	Mud	15.6%	29.2%	23.0%	28.2%	28.2%	26.5%	12.0%	17.5%	4.8%	28.9%

Sample Code		SD-21	SD-22	SD-23	SD-24	SD-25	SD-26	SD-27	SD-28	SD-29	SD-30
FOLK AND WARD METHOD (Description)	MEAN:	1140.7	1458.8	573.8	584.6	330.6	1883.5	494.5	1105.9	628.4	104.9
	SORTING:	5.578	4.655	2.083	6.773	1.437	4.298	2.273	4.407	6.446	2.936
	SKEWNESS:	0.232	-0.027	0.282	-0.006	0.217	0.032	0.304	-2.098	-0.222	0.593
	KURTOSIS:	0.970	0.687	0.771	0.312	2.039	0.559	0.835	0.348	0.303	0.923
FOLK AND WARD METHOD (Description)	MEAN:	Very Coarse Sand	Very Coarse Sand	Coarse Sand	Coarse Sand	Medium Sand	Very Coarse Sand	Medium Sand	Very Coarse Sand	Coarse Sand	Very Fine Sand
	SORTING:	Very Poorly Sorted	Very Poorly Sorted	Poorly Sorted	Very Poorly Sorted	Moderately Well Sorted	Very Poorly Sorted	Poorly Sorted	Very Poorly Sorted	Very Poorly Sorted	Poorly Sorted
	SKEWNESS:	Coarse Skewed	Symmetrical	Coarse Skewed	Symmetrical	Coarse Skewed	Symmetrical	Very Coarse Skewed	Very Fine Skewed	Fine Skewed	Very Coarse Skewed
	KURTOSIS:	Mesokurtic	Platykurtic	Platykurtic	Very Platykurtic	Very Leptokurtic	Very Platykurtic	Platykurtic	Very Platykurtic	Very Platykurtic	Mesokurtic
Percentage	Gravel	29.6%	31.6%	3.9%	34.2%	0.3%	46.8%	4.7%	56.2%	39.9%	4.3%
	Sand	59.2%	61.8%	95.0%	38.0%	99.7%	51.2%	94.5%	14.9%	30.7%	56.8%
	Mud	11.1%	6.6%	1.0%	27.7%	0.0%	1.9%	0.8%	28.9%	29.4%	38.9%

CONCLUSIONS

The sediment texture characteristics of most of the bed load in the study area is classified as very fine sand. Statistically, the fraction is dominated by sand, which ranges from 11.8% to 92.2%. The sediment gradation varies, with some portions classified as good due to grain size variations. The average sediment grain size falls within the range of 261.1 µm to 2657.5 µm. Overall, the sorting is predominantly very poorly sorted, indicating an environment dominated by fine-grained sediment and relatively weak currents. The sediment distribution curve is classified as very platykurtic, suggesting dominance of a specific grain size, particularly very fine sand sediment. These findings indicate that the bed load in these waters has good soil bearing capacity, making it highly suitable for port revitalization.

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