ASSESSMENT OF SEDIMENT OVERFLOW AND DISPERSION DYNAMICS FROM CUTTER SUCTION DREDGER-BARGE OPERATIONS IN A HIGH-TIDAL FLUVIAL SYSTEM: A CASE STUDY OF THE PUSSUR RIVER, BANGLADESH

Motiur Rahman*[1], Md. Shahjahan Ali[2] and M. Mubtasim Fuad Dip[3]

[1] *Executive Engineer, Mongla Port Authority, Bangladesh, Country, e-mail: khan.motiur06@gmail.com*
[2] *Professor, Khulna University of Engineering & Technology, Bangladesh, e-mail: msali@ce.kuet.ac.bd*
[3] *Lecturer, Khulna University of Engineering & Technology, Bangladesh, e-mail: dip@ce.kuet.ac.bd*

***Corresponding Author**

ABSTRACT

Maintenance dredging for the Pussur River is complicated by the high cost of utilizing specialized Trailing Suction Hopper Dredgers (TSHDs) and severe scarcity of nearby disposal sites due as the channel is bordered by the Sundarbans mangrove forest. To address this, the Mongla Port Authority adopted a cost-effective alternative: smaller Cutter Suction Dredgers (CSD) integrated with barge loading and transport system. This strategy, while financially prudent, necessitated a rigorous scientific assessment to quantify the resulting sediment overflow during barge loading and determine the hydrodynamic fate of the discharged material, thereby establishing the system's long-term sustainability and operational risk. A comprehensive field investigation was conducted on two active dredging sections (Confluence Channel-3 and Mooring Buoy-1). The methodology included concurrent field sampling of dredged material and overflow discharge, along with in-situ flow velocity measurements across the full tidal cycle. Laboratory analysis quantified the Total Sediment (TS) concentration to calculate overflow percentage and determined the Particle Size Distribution (PSD) of the overflow material. These empirical data, combined with established settling velocities, were integrated into a two-dimensional vector analysis model to simulate the resultant sediment transport distance and vertical settling depth over the tidal cycle.

Analysis showed the overflow loss consistently ranged between 21% and 26%, which is significantly below the typical 30% to 40% loss often reported for TSHD overflow, validating the system's efficiency from a mass-loss perspective. Sediment characterization revealed the overflow is overwhelmingly fine cohesive material, with clay and silt collectively constituting over 97% of the volume. The non-cohesive fine sand component (1.6% to 2.3%) was minimal. Settling velocities were established as 0.1 mm/s for clay-silt and 5 mm/s for fine sand. The vector model demonstrated that the strong tidal currents (peaking near 1.0 m/s) overwhelmingly dominate the transport, effectively rendering the already low particle settling velocity negligible for the fine fraction. The modeling confirmed that the minor fine sand fraction settles rapidly, impacting the riverbed within approximately 200 meters of the overflow point, posing a negligible risk to the channel. Conversely, the dominant clay-silt fraction is subjected to exceptional long-distance dispersal, travelling approximately 21.6 kilometers during a single high-flow tidal phase and only settling a cumulative total of 4.03 meters across the average 9.25 meter water column. This high dispersal, further enhanced by tidal-driven turbulent resuspension, confirms that the vast majority of the overflow is effectively flushed away from the immediate dredged area. This research validates the CSD-barge system as an operationally effective and financially prudent alternative for maintenance dredging, providing scientific justification that the natural hydrodynamic dispersal mechanism in the Pussur River is sufficient to mitigate re-deposition risk, thus securing the long-term navigational depth.

Keywords: *Pussur River, dredging, sediment, overflow, deposition*

1. INTRODUCTION

Mongla Port, the second seaport of Bangladesh is located in the southwest region of Bangladesh, which plays a vital role to the economy of Bangladesh (Ali & Rahman, 2023). Pussur river, a complex river system in this region is the access channel to Mongla Port (Rahman & Ali, 2022). Pussur river is dominated by tidal flows where fresh water flow from upstream is much less. The length of Pussur river from Bay of Bengal to Mongla Port is approximately 110 km (Rahman & Ali, 2024). Among this stretch, around 35 km requires continuous maintenance dredging. Management of dredged material is a big challenge for Mongla Port, because around 90% land on both side of Pussur River is surrounded by the Sundarbans. To manage the dredge material, it needs to transport too far away because of scarcity of shore dumping area adjacent to dredging area. The most common method to transport the dredged material far away from the dredging area is using Trailing Suction Hopper Dredger (TSHD) (Bai et al., 2020). In Bangladesh, TSHD is not easily available and most common type of dredger used is Cutter Suction Dredger (CSD). The cost associated with dredging by TSHD is approximately twice than CSD. Due to high cost, using TSHD is not always feasible for dredging in Pussur river.

Dredged material from cutter suction dredger also could be transported using barge. The process of dredging with a cutter suction dredger (CSD) and transporting the material via a barge involves excavation, suction, internal pumping into the barge's hold, and then the independent transport and disposal of the material by the barge. This method is typically chosen when the disposal site is too far for direct pipeline transport (IADC, 2014). The primary mechanism for disposing of dredged material from a CSD involves a fundamental trade-off between the continuous hydraulic transport via pipeline and the batch-based mechanical transport via barge, with the selection being dictated by the project's economic break-even distance (Bray, 2008). Direct pumping through a floating pipeline is the best way to get materials to a nearby shore or reclamation area. This is usually the cheapest option for shorter distances, especially those less than 3,000 meters (Vlasblom, 2005). This method allows for continuous production, which means fewer breaks and a steady flow of slurry. But as the distance to the disposal site grows, the total capital and operational costs for the pipeline method go up a lot because it needs to be installed with several intermediate booster stations to keep the flow rate and pressure at the right levels (Bray, 2008). Consequently, when the distances are much longer or the final placement site is offshore, the operational model changes to the more cost-effective barge-loading system (Vlasblom, 2005). When distance is the most important factor, barges are cheaper per unit volume than pipelines and booster systems (U.S. Army Corps of Engineers, 2015). This strategic choice makes sure that the project moves forward in the "least costly, environmentally acceptable manner" that is in line with good engineering practice (Engler et al., 1988, as cited in U.S. Army Corps of Engineers, 2015).

Presently, Mongla Port Authority (MPA) is conducting the dredging in the Inner bar area of Pussur River. Inner Bar is located between Harbaria and Port Jetty. MPA has appointed JHCEC-CCECC JV as contractor of this dredging. At the beginning of the dredging project, the contractor has engaged much larger size CSD (Capacity 6500 m^3/hr). However, due to scarcity of disposal areas, those dredgers could not be utilized continuously. Then the contractor took back those dredgers and introduced a new technology of dredging. In the new methods, small CSD's (Capacity 450-500 m^3/hr) are being used after installation of barge loading system. In this method, dredged material is loaded into barge from CSD and then transported to shore disposal area, which is around 5-10km away from the dredging area (Figure-1). During the loading on barge, certain amount of sediment overflow from it (Figure-2). The assessment of percentage of overflow sediment and settling velocity with distance is required to evaluate the performance of this new dredging method.

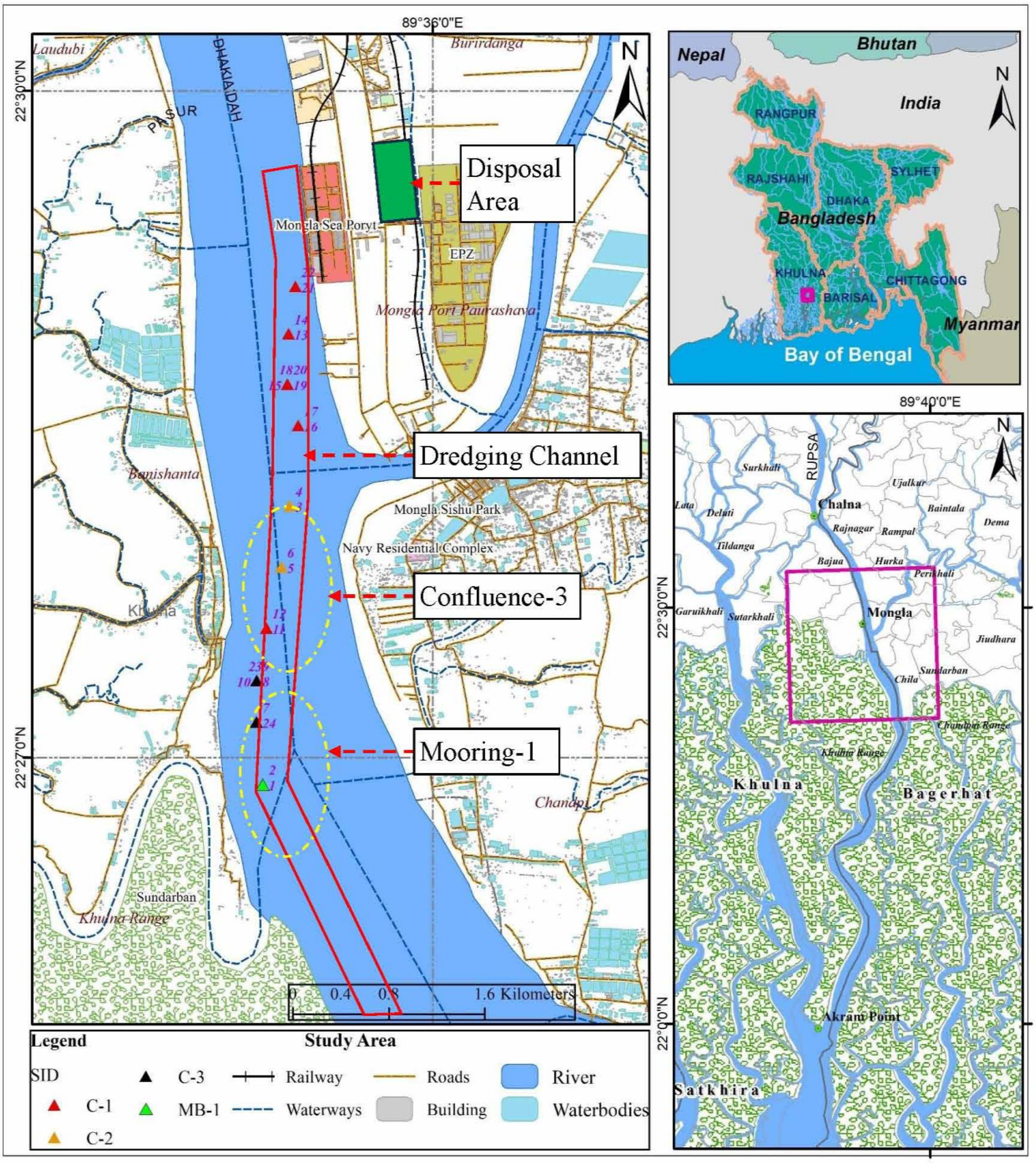


Figure 1: Study area showing dredged section, sampling area and disposal area.

2. METHODOLOGY

The performance assessment of the dredging method was executed in the Inner Bar area of the Pussur River, the critical access channel for Mongla Port. This river system is characterized by being tidally dominated, with the section requiring continuous maintenance dredging spanning approximately 35 km. The specific areas of investigation during field observation were Confluence Channel-3 and the Mooring Buoy-1 area, both situated between the MPA Jetty and Joymonirgoal.

The methodology involved a comprehensive field investigation and subsequent laboratory analysis. Data collection included retrieving dredged samples, overflow samples from the barge, and river water samples at various upstream and downstream locations. River flow velocity was also measured at the dredging sites. Total Sediment (TS) concentration was tested using a conductivity meter and hydrometer for the dredged and overflow materials to quantify the percentage of sediment lost due to overflow. Sieve and hydrometer analyses were performed on the overflow sediment to determine the composition of clay, silt, and sand, which is critical for assessing the efficiency and environmental fate of the material. Based on established settling velocities for clay-silt and fine sand, the resultant velocity (R) and angle (θ) of the sediment particles were calculated using vector analysis with the measured flow velocity and particle settling velocity using the following equations:

$$\text{Resultant, R} = \sqrt{(\mathrm{V1}^2 + \mathrm{V2}^2)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Angle\ with\ V2, \theta = \tan^{-1}\frac{V1}{V2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

This kinematic model was applied across the tidal cycle (Slag, Rising, and Falling periods) to calculate the sediment transport distance and vertical settlement to assess the potential for re-deposition within the channel.

(a) Dredged material filling the barge (b) Spilling of mud-mix water into the river

Figure 2. Dredging using CSD integrated with Barge Loading system

3. RESULT AND DISCUSSION

3.1 Sediment concentration of Inflow and Overflow samples

The sediment concentration of dredged sample, overflow sample and river water has been tested through conductivity meter and hydrometer. Total sediment concentration of dredged sample and overflow sample is presented in Table 2. The test result shows that, total sediment concentration of two dredged samples at Confluence channel-3 area was 1,55,540.00 mg/L and 2,98,770.00 mg/L, whereas concentration of overflow sample is 36,550.00 mg/L and 79,510.00. The percentage of overflow sediment is 23.5% and 26.61%. On the other hand, total sediment concentration of two dredged samples at Mooring Buoy-1 area was 1,24,790.00 mg/L and 3,72,170.00 mg/L, whereas concentration of overflow sample is 26,410.00 mg/L and 82,960.00. The percentage of overflow sediment is 21.16% and 22.29%. According to Rhee (2002), Depending on the particle size distribution (PSD) of the sediment, the hopper geometry and other process parameters this overflow loss from TSHD can reach values up to 30-40 % of total volume dredged. The overflow loss of sediment as stated earlier lies 21~26% of inflow, which is less than the loss from TSHD.

Table 2: Total Sediment (TS) concentration of samples

Serial	Location	Total Sediment (TS) Concentration (mg/L)			
		Dredged Sample	Overflow Sample	% Overflow	Average % Overflow
1	Confluence Channel-3	1,55,540.00	36,550.00	23.50%	25.06%
2	Confluence Channel-3	2,98,770.00	79,510.00	26.61%	
3	Mooring Buoy-1	1,24,790.00	26,410.00	21.16%	21.73%
4	Mooring Buoy-1	3,72,170.00	82,960.00	22.29%	

3.2 Particle Size and Setling velocity

3.2.1 Particle size analysis

The particle size of overflow sediment plays an important role in the assessment of dredging method efficiency. Normally smaller particles stays as suspension in the water having less possibility of settlement on river bed. However, coarse particle could settle much quickly on river bed. The particle size has been analysed through sieve and hydrometer analysis. The result of combined analysis is presented in Table 3.

The overflow sediment consists mainly clay and silt (around 97.70%) and much less amount of fine sand (2.3%). The GSD curve of one sample is presented in Figure 3. According to the reports received from JHCEC-CCECC JV, the dredged quantity in was around 10,00,000.00 cu.m and 12,00,000.00 cu.m in Confluence Channel-3 and Mooring Buoy-1 area. According to their future plan, about 10,000,000 cu.m of sediment will be dredged in this method. Based on the percentage of overflow, the quantity of different types of soil overflowed from each section is presented in Table 4 & 5.

Table-3: Percentage of clay, silt and sand in the overflow material

Serial	Sampling Area	Condition	% of clay	% of silt	% of fine sand	% of medium sand
1	Confluence-3	Over Flow Full Load	40.36	58.74	0.90	0
2	Confluence-3	Over Flow Half Load	22.55	75.15	2.30	0
		Average of Confluence-3 =	31.45	66.95	1.6	0
3	Mooring Buoy-1	Over Flow Full Load	39.46	58.24	2.30	0
4	Mooring Buoy-1	Over Flow Half Load	22.55	75.15	2.30	0

Average of Mooring Buoy-1 =	31.01	66.70	2.30	0

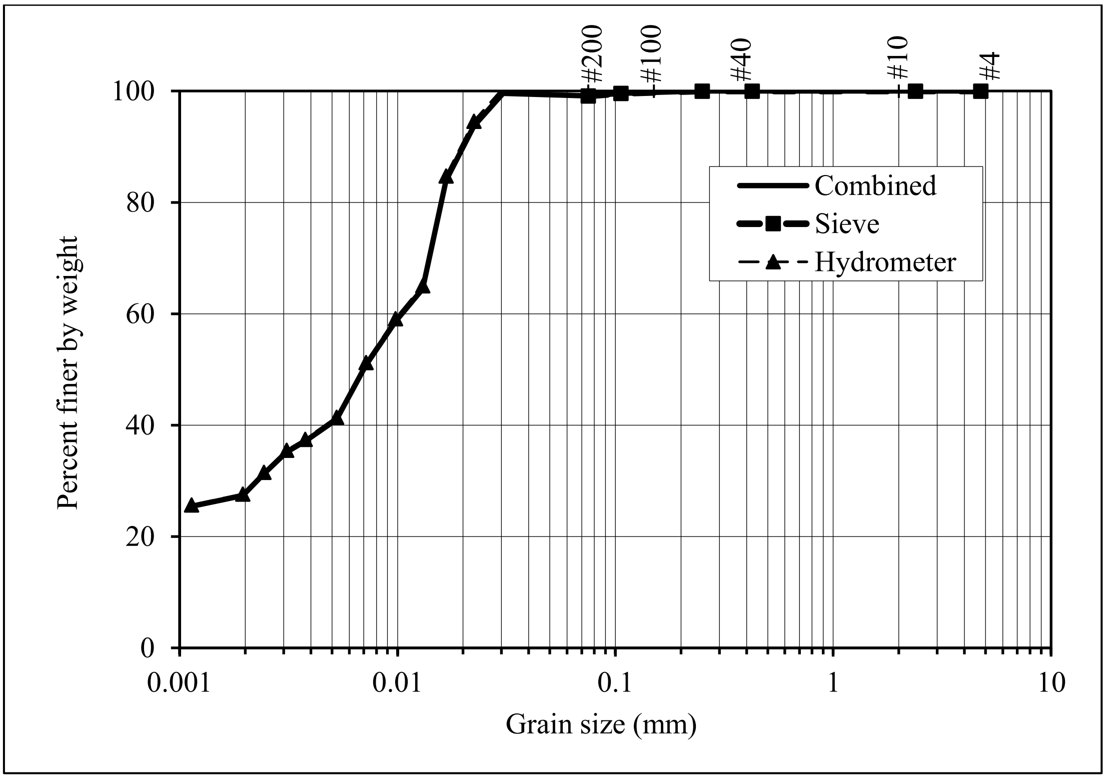


Figure 3: Grain size distribution curve of overflow material at Confluence Channel-3

Table 4: Quantity of soil overflowed from Confluence-3 dredged section.

Dredged Area	Dredged Quantity, m^3	% Overflow	Overflow Quantity, m^3	Amount of Clay, m^3 (31.45%)	Amount of Silt, m^3 (66.95%)	Amount of Fine sand, m^3 (1.6%)
Confluence-3	10,00,000	25.06	2,50,600	78,814	1,67,777	4,009

Table 5: Quantity of soil overflowed from Mooring Buoy-1 dredged section.

Dredged Area	Dredged Quantity, m^3	% Overflow	Overflow Quantity, m^3	Amount of Clay, m^3 (31.01%)	Amount of Silt, m^3 (66.70%)	Amount of Fine sand, m^3 (2.3%)
Mooring Buoy-1	12,00,000	21.73	2,60,760	80,862	1,73,927	5,971

3.2.2 Settling velocity analysis

Van Rijn (2020) has analysed the settling velocity of several samples collected from Rabnabad Channel at Kalapara in Patuakhali, Bangladesh. According to that study, the settling velocity of clay and fine silt is approximately 0.1 mm/s, whereas the settling velocity of fine sand is approximately 5 mm/s. This settling velocity has been used in the present study for further analysis. The dredged depth in Pussur river is 7.5m CD. Chart datum level is very close to low water level and during high tide, water level increases by around 3.5m. Considering the tidal changes, the available water depth will be 7.5m in ebb, 11m; i.e. average 9.25 m. The measured flow velocity of Pussur river could be divided in three group considering the tidal cycle, which are: (a) Slag period-M1, (b) rising period-M2 and (c) falling period-M3 as shown in Figure 4.

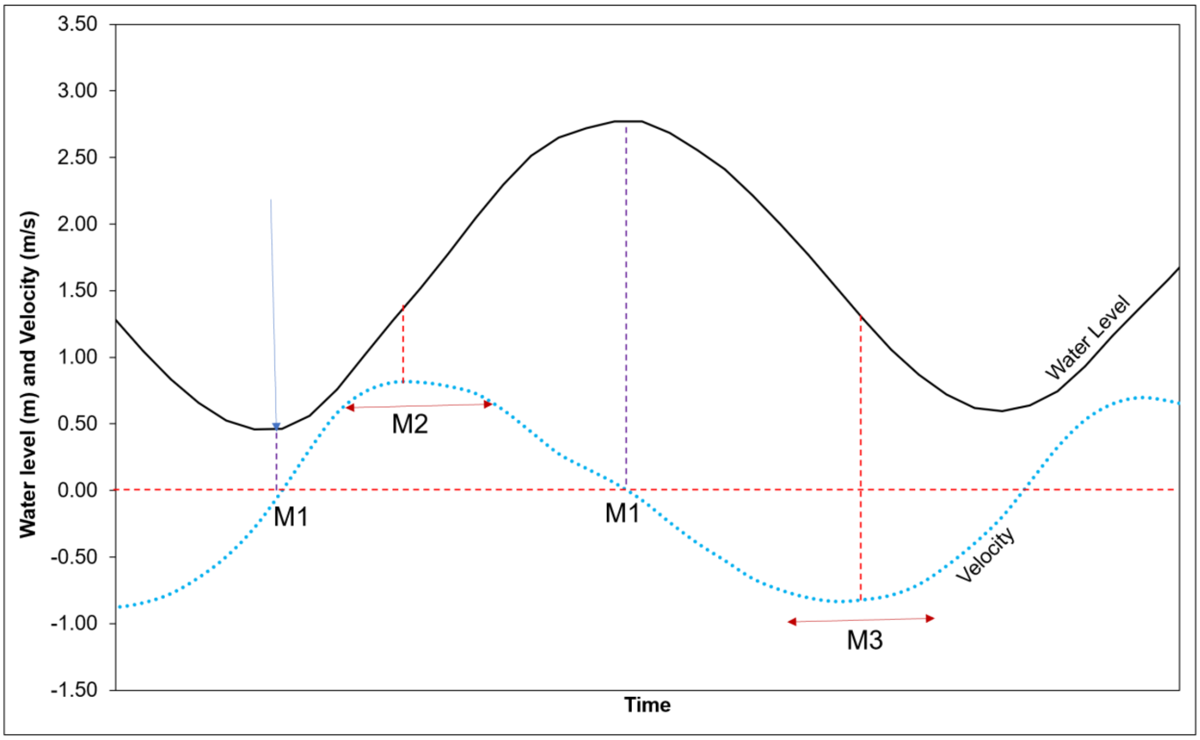
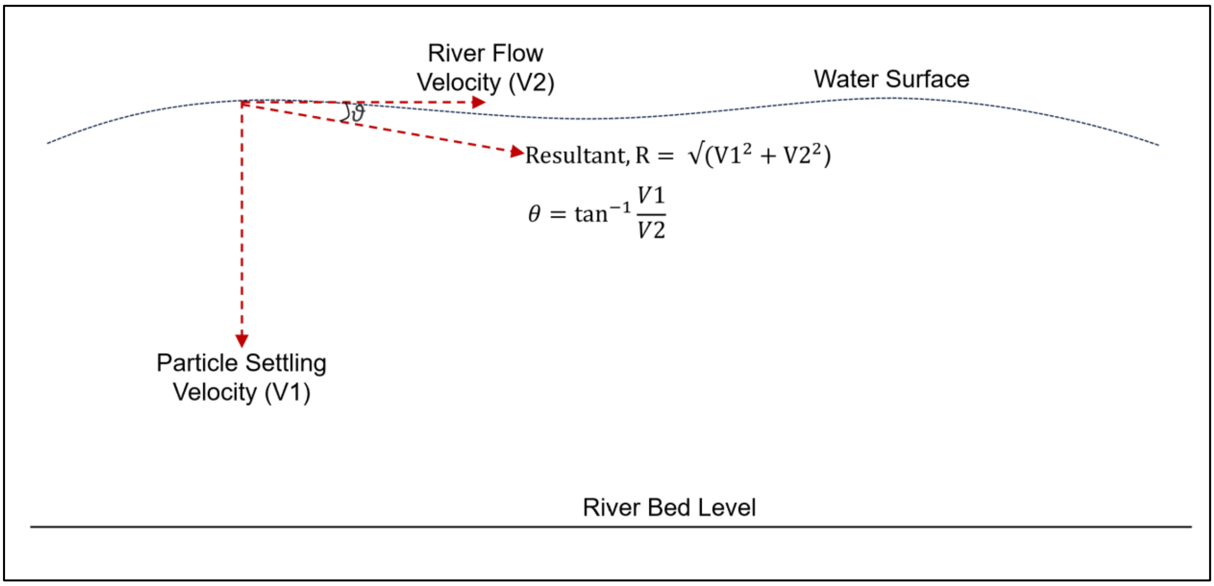


Figure 4: Different phases of tidal cycle and corresponding velocity



$$\text{Resultant, } R = \sqrt{(V1^2 + V2^2)}$$

$$\theta = \tan^{-1}\frac{V1}{V2}$$

Figure 5: Schematic diagram of settling velocity, flow velocity and river depth

The velocity at M1 phase is almost zero, consider 0.05 m/s and duration of this phase is around 30 minutes. The velocity of M2 and M3 phase covers around 12 hours of tidal cycle (6 hours each) and the velocity in this time are almost identical which is around 1 m/s. The settling velocity of sediment and corresponding sediment transport has been calculated for these two groups. The settling velocity (V1) vector of sediment and flow velocity vector (V2) have almost 90^0 angles. A schematic diagram of settling velocity, flow velocity and river depth is presented in Figure 5. The resultant of two vector (V1 & V2) and direction can be calculated using the equation-1&2. The resultant vector and its angle has been calculated for caly-silt and fine sand particles which is presented in Table 6.

Table 6: Resultant velocity and direction of sediment particle.

Serial	Tidal Phase	Resultant for Silt-Clay (Settling velocity 0.0001 m/s)		Resultant for Fine Sand (Settling velocity 0.005 m/s)	
		Resultant Velocity, R (m/s)	Angle with flow velocity, R (Degree)	Resultant Velocity (m/s)	Angle with flow velocity (Degree)
1	Slag period-M1 (Flow velocity 0.05 m/s)	0.0500001 ≈ 0.05	0.11^0	0.0502 ≈ 0.05	5.7^0
2	Rising and Falling Period- M2&M3 (Flow velocity 1.0 m/s)	1.0	0.01^0	1.0	0.29^0

The combined magnitude of sediment is dominated by flow velocity and effect of sediment settling velocity is almost negligible. During the M1 period, resultant velocity of sediment silt-clay particle is 0.05 m/s at an angle of 0.11^0 with the water surface. In M2&M3 period, the velocity is 1.0 m/s at an angle of 0.01^0 with water surface. For fine sand, the resultant velocity is 0.05 m/s and 1.0 m/s at a angle of 5.7^0 and 0.29^0 during M1 and M2&M3 period respectively.

3.2.3 Sediment Transport analysis

The main objective of the of this study is to assess the possibility of settling the overflow sediment in the channel or dredged area. According to the discussion in previous section, sediment transport is dominated by flow velocity rather than particle settling velocity. The angle of sediment transport for clay-silt is also negligible, however for fine sand the angle is considerable. Based on the resultant velocity and angle, the sediment transport distance has been calculated which is presented in Table 7. The analysis of sediment transport has carried out considering the slag period in flood tide as the beginning of cycle. The settlement rate of clay-silt particle is considerably low. During the Flood slag period (M1) the clay-silt particle travel around 90 m and settled by 0.18m only. However, the fine sand settles by 8.1 m in that period. In M2 period, the clay-silt particles travel around 21.6 km and settles by 3.67m. The fine sand particles settle to river bed at the very beginning of M2 period. During the ebb slag period (M1) the clay-silt particlesas again settled by 0.18m. In the total cycle, the clay-silt particles settle total 4.03 m. But the fine sand settled to river bed within 200m of overflow point. However, the total quantity of fine sand is only 1.6% of total dredged material which is almost negligible. The clay-silt particles could resuspend during the next flood tide.

The mixing of clay and silt sediments in tidal rivers environments is powerfully driven by the turbulence generated during the cyclic transition between ebb and flood tides (Scully & Friedrichs, 2007). As tidal currents speed up, the bed shear stress rises above the cohesive forces that keep fine sediments on the seabed. This causes the sediments to be resuspended and carried into the water column. Turbulence makes this process stronger by moving the suspended sediment up and down through the water depth. Tidal asymmetry in turbulent mixing is often a key factor. For example, one phase (flood or ebb) may have a higher eddy viscosity because of density stratification (tidal straining).

Table 7: Sediment transport distance of sediment particle in different phases of tide.

Tidal Phase	Duration (s)	Transport of clay-silt		Transport of fine sand	
		Along flow direction, H (m) = R*s	Vertical distance, V = H*sin(θ)	Along flow direction, H (m) = R*s	Vertical distance, V = H*sin(θ)
M1 (R=0.05); ($\theta = 0.11^0$ and 5.7^0)	1,800 s	90 m	90*0.002 = 0.18 m	90 m	90*0.09 = 8.1 m
M2 (R=1); ($\theta = 0.01^0$ and 0.29^0)	21,600 s	21,600 m	21,600* 0.00017= 3.67	21,600 m	21,600* 0.005= 108
M3 (R=1); ($\theta = 0.01^0$ and 0.29^0)	21,600 s	21,600 m	21,600* 0.00017= 3.67	21,600 m	21,600* 0.005= 108

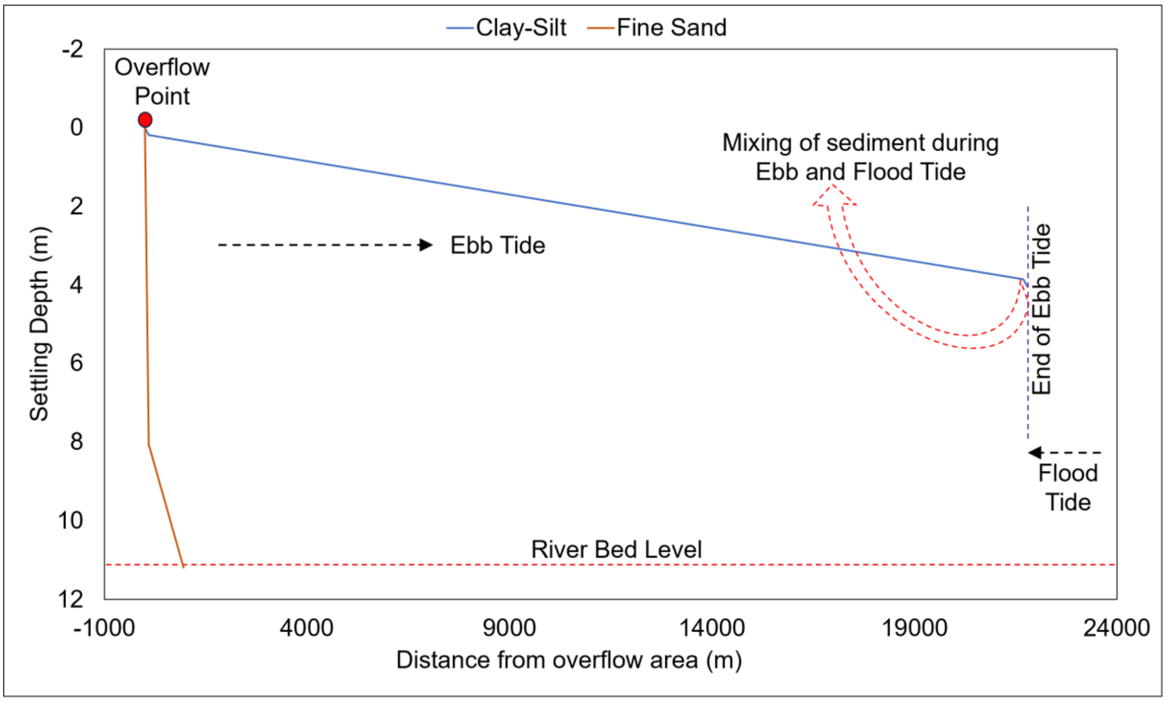


Figure 6: Settling of sediment particle

In some estuaries, the flood tide that is less stratified can be more turbulent. This can cause more sediment to be resuspended and moved up-estuary, even if the net flow is seaward. On the other hand, high turbulence can also break up fine sediment aggregates (flocs), which changes their settling speed and affects how they mix and spread throughout the tidal cycle (Ha & Maa, 2010).

3.2.4 Economic analysis

Bangladesh needs to dredge about 165.5 million cubic meters of material each year to keep its waterways in good shape. But the actual amount of dredging that can be done with the current capacity is much lower, about 84.6 million cubic meters per year (Bashir, 2022). Bangladesh's maritime sector is doing large-scale, planned dredging to keep its main ports open to larger international ships. This is very important for the country's economy. The 14.3 km long navigational channel at the Matarbari Deep Sea Port had to be dredged to a final depth of 16 meters so that Capesize and Panamax ships could dock (Bangladesh Shipping Agents' Association, n.d.; Matarbari Port, 2024). At the same time, the major seaports that are already in use are constantly getting silted up, which requires a lot of capital and maintenance dredging. The Mongla Port has a huge long-term project called "Performance-Based Maintenance Dredging" that will remove 34.75 million m3 of silt from different channel points over the course of five years (Bangladesh Sangbad Sangstha, 2025). The Payra Port also has a big new project planned to keep dredging the 75 Rabnabad channel, which will cost about Tk 31.74 billion over two years to keep the 10.5-meter draft (Insider Desk, 2025). These projects are a big national investment to protect and future-proof the country's sea-based trade infrastructure. Most of these dredging will be carried out using TSHD. Following the success of Mongla Port, the low cost alternative of TSHD, dredging with CSD and barge could be adopted which could save huge amount of investment cost of Bangladesh.

4. Conclusion

The use of small Cutter Suction Dredgers (CSD) with barge transport is concluded to be a pragmatic and cost-effective operational strategy for the Mongla Port's maintenance dredging, effectively circumventing the high costs and logistical difficulties associated with using TSHDs. The measurable overflow loss during the barge-loading process, which falls between 21% and 26%, is deemed a justifiable operational cost and remains below the typical overflow reported for TSHD. The ultimate environmental fate of the overflow sediment is dictated by particle size: the minor fraction of fine sand (1.6% to 2.3%) settles rapidly within 200 meters of the discharge point, posing a negligible risk to the channel. Conversely, the dominant clay and silt fraction (over 97%) is carried long distances by the strong tidal currents traveling over 21 kilometers during a single tidal phase due to its extremely low settling velocity. This high dispersion, coupled with the process of tidal turbulence and bed shear stress inducing resuspension, confirms that most of the overflow is effectively dispersed away from the dredged area, thus preventing significant re-deposition and ensuring the long-term effectiveness of the maintenance dredging effort. If this dredging method could be followed in seaports of Bangladesh, that will save a huge amount of investment cost of Government to its maritime sector.

Reference:

Ali, M. S., & Rahman, M. (2023). Target vessel for Mongla Port of Bangladesh: Navigational perspective. *AIP Conference Proceedings*, *2713*, 050017. https://doi.org/10.1063/5.0129747

Bai, S., Li, M., Song, L., Ren, Q., Qin, L., & Fu, J. (2020). Productivity analysis of trailing suction hopper dredgers using stacking strategy. *Automation in Construction*, *122*, 103470. https://doi.org/10.1016/j.autcon.2020.103470

Bashir, M. O. I. (2022). Application of Artificial Intelligence (AI) in dredging efficiency in Bangladesh. *Annals of Emerging Technologies in Computing*, *6*(1), 74–88. https://doi.org/10.33166/aetic.2022.01.005

Bray, R. N. (2008). *Dredging: A handbook for engineers*. Thomas Telford Publishing.

Bangladesh Shipping Agents' Association. (n.d.). *Matarbari Deep Sea Port*. Retrieved October 31, 2025, from https://bsaa.combd/matarbari-deep-sea-port

Bangladesh Sangbad Sangstha. (2025, June 3). *Dredging to resume soon at Mongla Port channel*. https://www.bssnews.net/others/279780

Ha, H. K., & Maa, J. P.-. (2010). Effects of suspended sediment concentration and turbulence on settling velocity of cohesive sediment. *Geosciences Journal*, *14*(2), 163–171. https://doi.org/10.1007/s12303-010-0016-2

Insider Desk. (2025, June 21). *Tk 46.62 billion dredging plan for Payra Port faces scrutiny*. Industry Insider. https://industryinsiderbd.com/tk-46-62-billion-dredging-plan-for-payra-port-faces-scrutiny/

Matarbari Port. (2024, February 25). In *Wikipedia*. https://en.wikipedia.org/wiki/Matarbari_Port

Rahman, M., & Ali, M. S. (2022). Morphological response of the Pussur River, Bangladesh to modern-day dredging: Implications for navigability. *Journal of Asian Earth Sciences X*, *7*, 100088. https://doi.org/10.1016/j.jaesx.2022.100088

Rahman, M., & Ali, M. S. (2024). Drivers of tidal flow variability in the Pussur fluvial estuary: A numerical study by HEC-RAS. *Heliyon*, *10*(4), e25662. https://doi.org/10.1016/j.heliyon.2024.e25662

Scully, M. E., & Friedrichs, C. T. (2007). Sediment pumping by tidal asymmetry in a partially mixed estuary. *Journal of Geophysical Research Atmospheres*, *112*(C7). https://doi.org/10.1029/2006jc003784

U.S. Army Corps of Engineers. (2015). *EM 1110-2-5025: Dredging and dredged material management*. U.S. Army Corps of Engineers.

Van Rijn, L. C. (2020). *Settling velocity and equivalent size of mud*. Retrieved from www.leovanrijn-sediment.com

Vlasblom, W. J. (2005). *Designing dredging equipment: Chapter 3: Cutter suction dredger*. Central Dredging Association.