Article

Maritime Literacy: Oceanic Significance in the Formation of the Bangladesh Delta

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The Bengal Delta is one of the largest and most dynamic delta systems in the world (Gupta, 2007). It plays a critical role in the geography, geomorphology, and ecology of Bangladesh and the Bay of Bengal (BoB) region. The sediment load carried by the Ganges, Brahmaputra, and Meghna rivers, which drains the most sediments from almost all of the Himalayas, has shaped this delta. This delta system is a testament to the powerful interaction between riverine processes, such as river discharge and river bank erosion, and marine processes, like tidal cycles, storm surges, etc. The role of the BoB's predominant semidiurnal tidal cycle is crucial in forming the Bengal Delta. There is also a compelling correlation between river discharge and sediment deposition.

The Bengal Delta has been shaped mainly by the sediment load from the foreslope and backslope of the Himalayas. This sediment load is carried by two Himalayan rivers: the Ganges and the Brahmaputra (Islam & Gnauck, 2008). Another major source of the sediment load is the non-Himalayan Meghna River. These three rivers, collectively called Ganges-Brahmaputra -Meghna (GBM) river system, have shaped and reformed several deltas before settling into their present-day formation, merging and emptying all sediments into the Bay of Bengal. The topset beds of an advancing and dynamic delta are deposited in turn over the previously laid delta sediments. Topsets are nearly level layers of sediment deposition on the top of the delta, forming an extension of the landward alluvial plain due to the sea-level jump in the Holocene period about 11,700 years ago (Hori & Saito, 2007). The delta formation has contributed to approximately 60% of Bangladesh's coastline (Shariot-Ullah et al., 2021). The delta can be divided into the inactive delta on the western part and the active Meghna deltaic plain on the eastern side, each with distinct geological features and significance.

Geological History and Development

The Ganges-Brahmaputra delta first developed around 125 million years ago (Ma) after the fragmentation of Gondwanaland and has continued to develop since the early Cretaceous (145-100.5 Ma) (Islam, 2016). This process has continued through various geological epochs, influenced by the activities of tectonic plates of the earth's crust, major sea level changes during the shifts of ice ages, and the rise of the

Himalayas, which is still ever-changing due to tectonic activity. The delta's evolutionary phases can be divided into the proto -delta, the transitional delta, and the modern delta (Celis, 2021).

• Proto-Delta (126-49.5 Ma): This stage was characterized by four major sequences of carbonate-clastic associations deposited in both restricted marine and open marine equatorial areas of the BoB.

• Transitional Delta (49.5-10.5 Ma): This stage was marked by the collision between the Indian and Eurasian plates after the fragmentation of Gondwanaland. It saw significant sediment deposition from the rising Himalayas.

• Modern Delta (10.5 Ma-Present): Following a major sea-level fall due to the ice age, the delta began to take its current form, dominated by the old river channels of the Ganges river system. Neotectonic activity and Quaternary sea-level fluctuations continue to shape and form the deltaic arcs.

Western Inactive and Eastern Active Delta

The western inactive delta includes districts such as Khulna, Satkhira, and Bagerhat in Bangladesh and covers approximately 31,500 square kilometers. This part is characterized by older geological formations, including the moribund, mature, and saline-tidal deltas, which have hardly any fluvial activity. Geologically younger and more dynamic eastern active delta covers about 15,000 square kilometers and includes districts like Barisal, Patuakhali, and Bhola. It is active mainly due to the high volume of river discharge through fluvial channels. The eastern active delta has a north-south length of about 300 kilometers and varying widths. The present size of the Bengal Delta is about 100,000 square kilometers (Akter et al., 2016).

The deltaic regions are almost flat, with elevations ranging from 15 meters in the northern part to nearly close to the sea level in the southern part. Tidal waves propagate approximately 200 km inland because the gradient is about 0.016 meters per kilometer (Bricheno et al., 2016). Bangladesh's deltaic plains are densely populated and highly fertile, which supports extensive agricultural activities. The major livelihoods of the local population are land cultivation, fishing, transportation, and collecting resources from the Sundarbans mangrove forest.

Role of the Ocean and River Dynamics

The Bengal Delta is a complex setting with diverse hydrodynamic processes, predominantly tidal cycles, and strong fluvial influences (Tonkin, 2012). With periodical variations, the semidiurnal tides, the massive seasonal fluxes of water during the monsoon seasons, and sediment from the river discharges interact to shape the delta (Celis, 2021). The sediments are primarily deposited on the sea floor, leading to the rise of the depositional plain and the current formation called the Bengal Fan, with a length of approximately 3000 km and a width of about 1000 km (Peketi et al., 2021). The ice melts during the interglacial stages, and the sea level rises. Then, the ocean processes intensify, and river processes are subducted by ocean processes, causing more deposition at river mouths (Munch et al., 2022).

An expansive Fluvial-to-Tidal Transition Zone (FTTZ) is established due to the highly dynamic nature of the Meghna deltaic plain results from the interaction between high fluvial discharge and significant tidal velocities (1-2 ms^{-1}) (Valentine & Wilson, 2023). Like in the case of Sandwip Island, morphologic changes in different areas around that island are driven predominantly by ocean processes like tidal currents. But in the case of Bhola Island, mainly the river currents influence the formation and changes. The erosion at Bhola depends on the precipitation rate over the region, and thus, this erosion process is mainly affected by the river discharge and is highly seasonal.

River Discharge and Sediment Deposition

The correlation between river discharge and sediment deposition area is complex. River discharge affects the deposition areas in the estuarine river channels and the Bengal Fan region. Generally, if river discharge increases, it will bring on more sediments, and the sediment deposition area increases to a certain threshold (Wang et al., 2012). Beyond this threshold, if the flow velocity of the river increases, the river flow turbulence can reduce the depositional areas despite the continued rise in discharge and sediment supply (Guo et al., 2018). This phenomenon was tested in Rabnabad Channel near the estuary by using numerical modeling. The input data was collected from the Payra Port Authority (PPA) and was used to run the model for predicting the area of deposition zones with hypothetical increased and decreased river discharge scenarios (Figure 01). It can be easily said that the dynamics of sediment transport and deposition are crucial for understanding the delta's evolution.

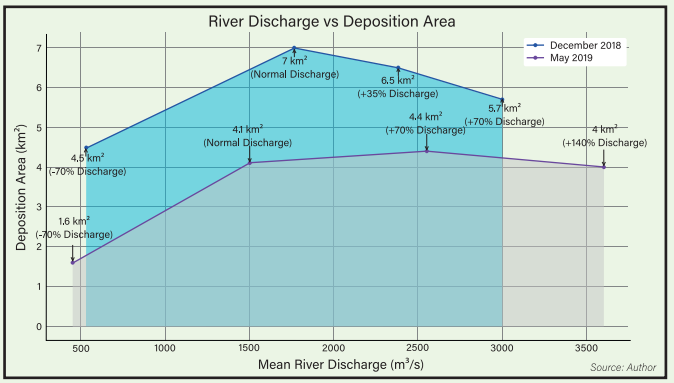

Figure 01. Graph showing correlation plot between mean river discharge (m^3/s) and deposition area (km^2) in Rabnabad Channel utilizing numerical modeling.

Climate Change and Its Impact on the Bengal Delta

Climate change significantly threatens the Bengal Delta by hindering normal sea level fluctuations and coastal processes. Due to climate change, the global temperature is rising, and it is melting the polar ice caps which causes sea level rise. The rising sea levels are prompting the hindrance of freshwater runoff and creating increased saltwater intrusion into freshwater resources, adversely affecting agriculture and drinking

water supplies (Rahman et al., 2022). The change in weather patterns, with prolonged dry spells and more intense monsoons, disrupts standard river discharge patterns and affects sediment supply. However, it also affects the fluvial process and triggers abnormal sediment deposition and erosion. Climate change enables more frequent and intense cyclones coupled with storm surges, which leads to more significant coastal erosion and displacement of coastal communities (Dasgupta et al., 2023). Additionally, the loss of biodiversity in the Sundarbans mangrove forest due to anomalies in Sea Surface Temperature (SST), fluctuations in sedimentation, and habitat degradation further threatens the ecological balance of the delta (Chowdhury et al., 2021).

The Bengal Delta is a remarkable example and masterpiece of nature. It has been divinely created and continuously reshaped by the interplay between riverine and marine processes in an equatorial coastal landscape. About 80% of Bangladesh is deltaic. Understanding the formation and dynamics of the delta is highly significant for maintaining the environmental and socio-economic challenges faced by its densely populated community. Scientific assessment of the dynamics, influencing the Bengal Delta, is of utmost importance. It is significant to design a long-term master plan like Bangladesh Delta Plan 2100 to utilize the full potential of the Blue Economy. Advanced and comprehensive data collection, construction of Marine Spatial Data Infrastructure (MSDI), and proper monitoring of the geomorphological changes of the delta can contribute to enhancing maritime literacy in Bangladesh. This would assist in addressing the impacts of climate change, sea level rise, and anthropogenic activities. To forecast the delta's geomorphological changes, the numerical modeling approach can give dividends to these spatial and oceanographic data. These research outcomes are key to conducting an Environmental Impact Assessment (EIA) and Economic Sustainability Assessment (ESA) during any type of coastal urbanization and infrastructure development for a prosperous Bangladesh.

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