LONG-TERM MORPHOLOGICAL CHANGES AND STABILITY OF SANDWIP CHAR ISLANDS: INSIGHTS FROM A 30-YEAR GEOSPATIAL ANALYSIS (1995–2025)

S. H. Sahim*[1], A. Karmakar [2] and T. K. Esh [3]

[1] *Undergraduate Student, Chittagong University of Engineering and Technology, Bangladesh, e-mail: saifulhossensahim2002@gmail.com*
[2] *Undergraduate Student, Chittagong University of Engineering and Technology, Bangladesh, e-mail: karmakarananta01@gmail.com*
[3] *Undergraduate Student, Chittagong University of Engineering and Technology, Bangladesh, e-mail: eshtanmoy@gmail.com*

***Corresponding Author**

ABSTRACT

The riverine and deltaic systems around the globe are highly dynamic habitats that are constantly restructured by the fluvial discharge, sedimentation, tide, and rising of sea level. In Bangladesh, this dynamism defines the areas along the coast like the Sandwip Char, located in a vast delta of the Ganges, Brahmaputra, Meghna (GBM) which has made it a centre of human habitation as well as a centre of susceptibility.This study conducts a thirty-year (1995-2025) geomorphological change analysis and stability of the charlands of an Sandwip island region to fill very critical gaps of knowledge on long-term erosion, accretion, and spatial heterogeneity of stable and unstable land. Based on multi-temporal Landsat data, change-detection processes that are done using landsat imagery in ArcGIS, and the Charland Presence Frequency (CPF) index, the research maps erosional and accretional trends and measures how sediment processes have contributed to the stability of the areas. The outcome of the study shows that the process of accretion has dominated the course of erosion over the course of the study, especially between the years 2015 and 2025 that has resulted in the significant increase in the total area of the land as well as, the transformation of the areas that were previously weak into the more stable land classes. However, new territories that are acquired are prone to tidal waves and weather extremes, which highlight the continuity of flux in the coastal context. This study will notifies the policy makers, planners and local stakeholders about safe settlement expansion, disaster risk reduction, and resource allocation. It also exposes the importance of combined surveillance and dynamic strategies in coastal resiliency considering Bangladesh Delta Plan 2100 against the background of intensifying climate change and human activities. Finally, the study contributes to the geomorphic understanding and is a strong framework of decision support in sustainable development and climate adaptation in the dynamic deltaic environment of Bangladesh.

Keywords: *Char Land Evolution, Coastal Stability, Sedimentation, Remote Sensing, Sandwip*

1. INTRODUCTION

Riverine and deltaic systems all over the world are inherently dynamic, the morphology of which constantly is adjusted by the interaction of fluvial discharge, sediment deposition, tidal forces and sea-level changes. In these settings, the islands and sandbars constantly change by erosion and accretion, and thus, an example of a very fragile balance between the land formation and erosion. The Ganges, Brahmaputra, Meghna (GBM) Delta is one of the most active and widespread sedimentary systems on earth; and its dynamics can be described as a result of the redistribution of huge loads of sediment due to erosion of the Himalayas and controlled by tidal processes and river processes. These processes have created a complicated net of moving channels, estuaries, and temporary char islands The geomorphic processes of deltaic systems, including, but not limited to, the GBM, are not only indicative of the natural variability, but also importantly of human vulnerability, since the processes play a crucial role in determining the stability and habitable nature of the related landforms. Transient sand or silt islands (called chars) that occur and disappear in river channels and estuarine environments have morphologies that are controlled by river discharge, sediment supply, storm surges, and tidal currents (Syvitski et al., 2009a). These formations are among the most active environments on the planet, both supplying the planet with a new land to settle and farm on, and posing a great risk to the environment.

The Sandwip Island and the associated char regions are located in the complex deltaic setting, and represent the overall dynamism in the GBM Delta. The island is situated on a geopolitically weak location in the south east coast of Bangladesh between the Meghna Estuary and the Bay of Bengal. It is demarcated by active tidal channels and is affected by both riverine outflow and coastal hydrodynamics such as tidal swings, sediment transportation, cyclonic storm surges and seasonal flooding (Tarafder et al., 2025). The processes keep on changing the coastline, altering char landforms, and the availability of land to human use. Low elevation and unconsolidated sediments contribute to morphological instability that has led over the last decades to the displacement of communities through erosion but also providing possibilities to accretion and reclaim new lands (Emran et al., 2017). Since the island has a socio-economic reliance on thousands of people, it is crucial to know how morphologies have changed.

The dynamism and complexity of the geomorphic development of deltaic systems have led to the introduction of long-term geospatial observation as a necessary measure to describe the system development appropriately. Even though short-term studies which concentrate on one event at a time like cyclones or floods are useful in understanding the event, they do not always help in realizing the cumulative effect of the interacting processes over a long period. It is proposed that a 30-year time projection (1995 to 2025) provides a sound system of recognising long-term morphological changes and patterns of char behaviour. A combination of remote sensing and Geographic Information Systems (GIS) facilitates objective and spatially explicit and constant observation of erosion and accretion processes, which supersedes the shortcomings of local ground surveys (Munasinghe et al., n.d.; Toa & Ali, 2022) (Munasinghe et al., n.d.). The approaches are especially useful in the GBM Delta, when the changes caused by sediment flux, seasonality, and hydrometeorological perturbations are fast and spatially discontinuous (Salter et al., 2022)

Despite the increased focus on the observation of the char lands, significant gaps are still present regarding the long-term morphological stability of the latter. Earlier studies have mainly been on short-term erosion processes, simulated sediment-transport, or individual measures of land loss. Multidecadal studies that capture the change detection and landform stability together are also few. Specifically, such a combination of erosion and accretion patterns and systematic stability assessment have not been performed in Sandwip Island and the surrounding chars. This is an important knowledge gap since the identification of whether the char system is undergoing net land gain or net land loss has serious consequences on the land management, disaster-risk reduction, and climate adaptation. In the current research, these issues are discussed by investigating: (1) spatial and temporal states of morphological changes in Sandwip chars in 1995 and 2025; (2) the areas prone to instability and long-term erosion; (3) net land-area change; and (4) using the Char Persistence-Frequency (CPF) approach to measure the stability under current climatic and hydrodynamic conditions (Khalil et al., 2024; Emran et al., 2017).

The main goal of the study is to conduct a multidecadal geospatial evaluation of the morphological change and stability of the char islands of Sandwip. This will involve measurements of erosion and accretion rates through multitemporal satellite data, spatial configurations to demarcate areas of instability and relative stability, net turnover of land-area, and morphological stability by the CPF approach. Through achieving these goals, the study will not only record the physical changes that have occurred to this deltaic environment but also provide a framework of analysis that can be used in future research studies and resource-management processes.

The importance of this work is not limited to the contribution to the geomorphology as the findings are vital to the policymakers, the local residents, as well as the general scientific community. As a form of information, the spatial distribution of the stable and unstable char areas informs land-use planning, disaster-risk reduction, and infrastructure development to policy and planning authorities concerned with such plans as the Bangladesh Delta Plan 2100. To the settlement inhabitants and the agricultural stakeholders, the insights will help the residents and agricultural stakeholders make more informed decisions on the settlement expansion as well as reclaiming any lost land, thus, minimizing the risk of land loss at any time. To the researchers, this piece of work contributes to the comprehension of the evolution of deltaic and the environmental change by providing empirical evidence of morphological behaviour and sustainability over an extended period of time. Furthermore, against the background of the accelerated climate change and rise in the sea level, it is expected that deltaic systems such as the GBM will experience an even greater change, which highlights the necessity of effective monitoring and adaptive measures (Aktar et al., 2025). Simply put, the char islands of Sandwip represent the contradiction of the deltaic setting, both land and erosion are in continuous motion. In examining 30 years of morphological change using the latest geospatial methods, and using stability measures based on CPF, the study aims at explaining the mechanisms behind this fine balance. The lessons learnt will be useful not only as scholarly work but also as a practical guideline to the people who are trying to cope with the changing realities of deltaic Bangladesh.

2. METHODOLOGY

2.1 Geographic Location

Sandwip Char region is an area located between 22°1618 your 2243 this area is the lower part of the Ganges, Brahmaputra, Meghna (GBM) delta, located in the southeastern part of Bangladesh between 22 1618 911737 E. It is part of Sandwip Upazila of Chattogram District and has an approximate area of 762 km 2, both including the main island and a number of neighbouring emergent chars like Urir Char and Magdhara Char. Geomorphologically, the area lies at tidal fluvial interface within the Meghna Estuary where strong tidal currents, annual river discharge, and storm surges that have their origin at the Bay of Bengal constantly rework its coastline (Aktar et al., 2025). The char lands are made of fine sand and silts which are very prone to erosion and accretion hence creating constant emergence and disappearance of islands. These dynamic processes directly affect settlement patterns, agricultural practices, and coastal resilience, which makes the Sandwip Char area one of the most morphologically dynamic but socio-economically populated areas in the deltaic terrain of Bangladesh. Figure 1 shows the area of Sandwip char derived from satellite image.

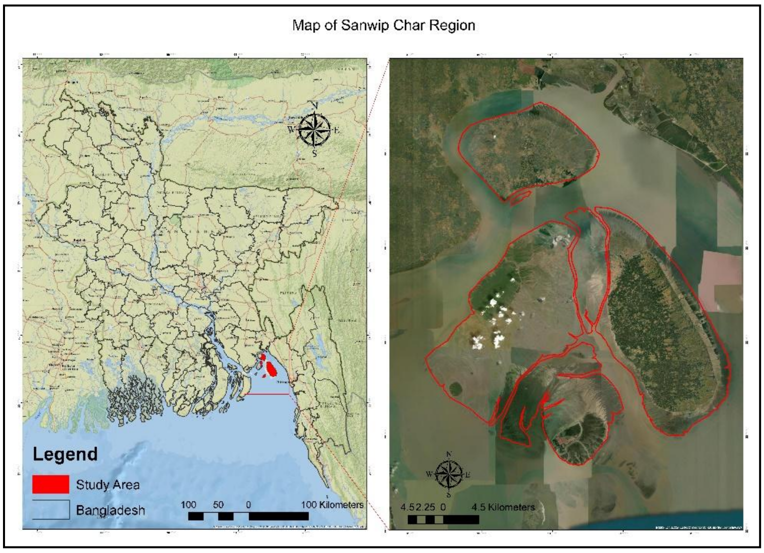

Figure 1: Location Map of Study Area

2.2 Materials

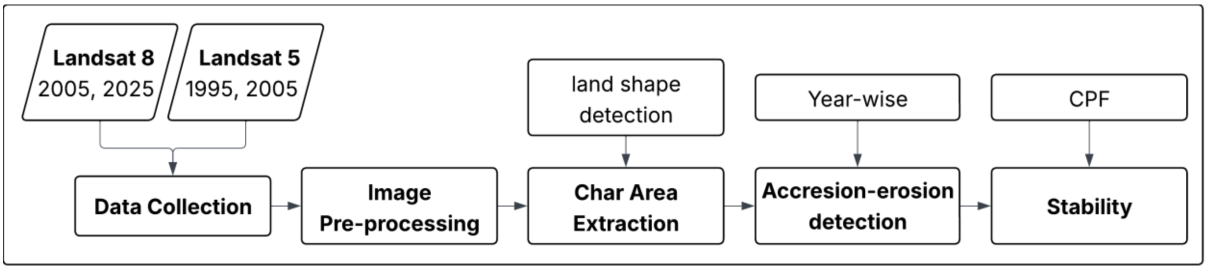

Figure 2: Methodology Flowchart

Satellite imaging is a useful instrument for obtaining in-depth surface observations of the Earth (Khorram et al. 2016). The study period is 30 years (1995-2025). Among these years, 4 particular years, 1995, 2005, 2015 and 2025, were chosen to compare the changes in the land area of Sandwip Charland. The images for 1995 and 2005 belong to Landsat 5 and for 2015 and 2025 the images belong to Landsat 8. The spatial resolution of these data is 30 m. The Landsat images were collected using GEE (Google Earth Engine) for the dry season, by doing essential atmospheric correction and carefully choosing the study area. The methodology flowchart of this study is shown in figure 2.

2.3 Methods For Charland Identification

The temporal change detection was conducted to identify the morphological changes in Sandwip charland using ArcGIS 10.8. This analysis involved comparing the shapes drawn around the land that clearly can be spotted in the satellite images. Then deriving the accretion and erosion of this land by comparing between consecutive years that were chosen, that is from 1995 to 2005, to 2005 to 2015 and to 2015 to 2025. This accretion and erosion analysis was done using ArcGIS. After that the stability of the Sandwip charland was identified using the CPF method. there is limited published work that uses a pixel-level charland presence frequency index (CPF) in remote-sensing time series, so we adopt/extend the concept used in waterbody frequency mapping (Pal et al., 2022) and apply it to charlands.

$$CPF_j = \frac{\sum_{i=1}^{n} CP_{i_i}}{N_i} \times 100$$

By using this procedure, this study provides an easy and accurate representation of the morphological changes occurring in Sandwip char, which will help to understand its dynamic landscape clearly.

3. RESULT

3.1 Identification of Charlands

The Sandwip area and an attached charland have been identified in the present study area. It was observed that the nearby charlands gradually combined due to sedimentation over years. It also can be observed from the figure 3 that the land area expanded most within last 10 years i.e. from 2015 to 2025.

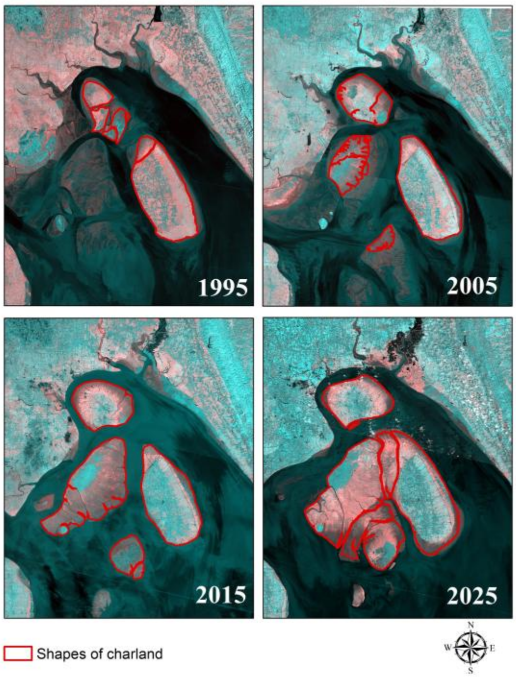

Figure 3: Year-wise area detection in Satellite images

From the area calculation of the erosion accretion, it was derived that the lowest erosion accretion occurred in 1995 to 2005- in these 10 years. By years, the erosion accretion phenomena gradually increased, and the 2015-2025 period contains the highest accumulation of sediment and highest rate of erosion. It can be seen from table 1 that the accretion rate is much higher than the erosion rate, and it went from 16922.34 hectors in 1995-2005 time period to 23002.17 hectors in 2005-2015 time period. This shows that sedimentation rate increased drastically within this period. The changes in area is shown graphically using bar diagram in figure 4.

Table 1: Area Calculation

Year	Unchanged (ha)	Erosion (ha)	Accretion (ha)
1995-2005	25214.9699	4169	16922.34
2005-2015	38290.7656	3846.547	23002.17
2015-2025	56356.8364	4936.096	24244.31

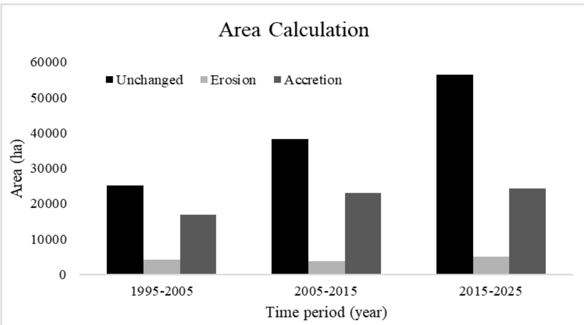

Figure 4: Area Calculation

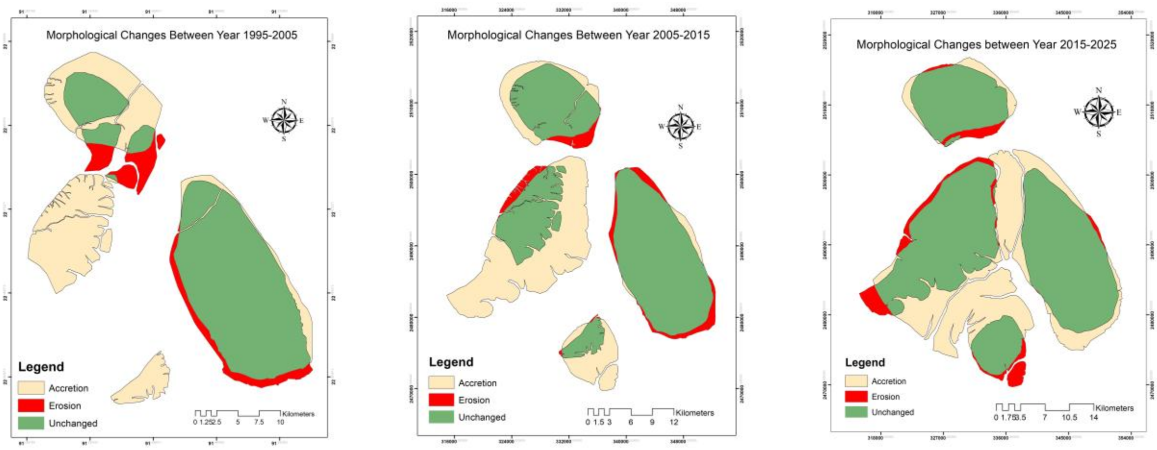

Figure 5: Morphological Changes of Sandwip Charland

The unchanged land and accretion rate gradually increased over years, as can be seen in figure 5, while erosion rate declined in 2005-2015, but again increased in 2015-2025 time period.

3.2 Stability

Table 2: Stability

Stability Class	**Area (Ha)**
Unstable	27181.06
Moderately Stable	23011.05
Stable	16512.72
Very Stable	22668.33

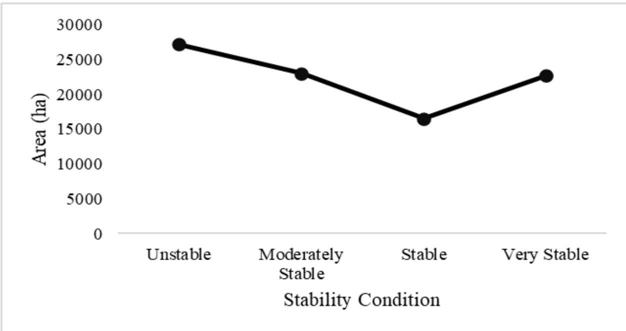

Figure 6: Stability Condition

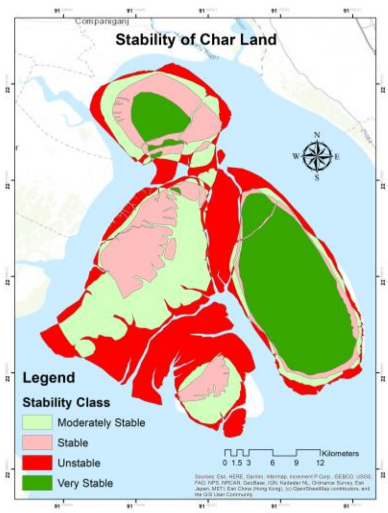

Figure 7: Stability Condition of Sandwip charland

The graphical representation of the stability condition is presented in figure 6 and the visual representation of the stability analysis is presented in figure 7. The stability rate of Sandwip was classified into four classes, namely unstable, moderately stable, stable and very stable. The analysis output in Table 2 shows that there is very stable area is about 22668.33 hectors, but there is more unstable area than very stable area, which is 27181.06 hectors. But the moderately stable and stable area makes up to an extent for the unstable part of the charland and the stable part is seen to be gradually increasing due to increased accretion rate.

4. DISCUSSION

The morphological analysis of Sandwip charland dynamic of 30 years shows a clear dominance of accretion over erosion, consistent with the long-term sedimentation trends in the Ganges-Brahmaputra-Meghna (GBM) delta. Every year, huge amount of sediment gets discharge from the GBM watershed, driven by recent intense monsoonal processes and upstream hydrology. This continues to reshape the coastal landscape of Bangladesh (Goodbred & Kuehl, 2000). This high level of sediment supply couples with tidal and estuarine interactions and results in rapid land formation and morphological instability, which aligns with previous observations in the Brahmaputra-Jamuna and Meghna estuaries (Sarker et al., 2014). The Charland Presence Frequency (CPF) approach effectively quantifies the spatial constancy of accreted and eroded zones, improving upon traditional change-detection analyses. These frequency-based mapping techniques, as used by Pal et al., (2022) for riverine land assessment, enables a more detailed understanding of geomorphic transition. The observed expansion of stable land over the last decade suggests progressive sediment consolidation, though newly accreted areas remain highly unstable due to tidal bores and storm surges (Tessler et al., 2015). The findings of this study shows that the total land area of Sandwip charland increased drastically in past 30 years from 1995 to 2025, which aligns with the findings of studies related to charland (Haque et al., 2025). The findings of this study carry significant value in implications of coastal management. Bangladesh's dynamic coastal zones are highly vulnerable to sea level rise and anthropogenic alterations, which may exacerbate erosion and salinity intrusion (Brammer, 2014; Syvitski et al., 2009b). But sustainable management of sedimentation processes offers opportunities for land reclamation and adaptation (Rashid et al., 2024). Understanding this morphologic and dynamic behavior is vital dor prioritizing safe settlement zone and planning future land use within the charlands and the deltaic system. In conclusion, this study underscores the need for integrated geomorphological monitoring frameworks that combine remote, field validation and hydrodynamic modelling to assess long-term coastal resilience (Khorram et al., 2016; Tessler et al., 2015). Coastal observation will be critical as Bangladesh's coastal systems is vulnerable to climate change and human interventions in the coming decades.

5. CONCLUSION

This study provides a comprehensive understanding of the geomorphic evolution and spatial stability of Sandwip charland over the past three decades. Through the application of multi-temporal remote sensing analysis and the Charland Presence Frequency (CPF) approach, it was found that accretional processes have dominated over erosion, indicating a steady trend of land expansion within the dynamic coastal environment. The results confirm that while new land continues to emerge through sediment deposition, these areas remain highly unstable and vulnerable to tidal and climatic influences. Such findings emphasize the importance of distinguishing between stable and unstable zones to guide sustainable land-use planning and resource management in coastal Bangladesh. The integration of CPF-based stability assessment offers a valuable framework for long-term monitoring of morphological changes and provides an effective tool for identifying potential areas for development or conservation. By linking geomorphic understanding with spatial planning, this approach supports improved decision-making for coastal zone management, disaster mitigation, and climate adaptation strategies. Adding field validation and advance analysis will further increase the importance of this study. Overall, the study contributes to a deeper insight into the natural processes shaping Bangladesh's coastal landscape and underscores the necessity of continuous observation and data-driven policy planning to ensure sustainable development in vulnerable deltaic regions.

REFERENCES

Aktar, S., Hossain, M., Rakib, Md. M. H., Saha, S. C., Ovi, M. H., Roy, D., Khan, A., Hasan, I., Salman, M. A., Khan, R., Rafiq, M. R., & Roy, D. K. (2025). Geomorphological responses to climate change in the Ganges-Brahmaputra-Meghna Delta: A multi-decadal remote sensing analysis. *Quaternary Science Advances*, *19*, 100296. https://doi.org/10.1016/j.qsa.2025.100296

Brammer, H. (2014). Bangladesh's dynamic coastal regions and sea-level rise. *Climate Risk Management*, *1*, 51–62. https://doi.org/10.1016/j.crm.2013.10.001

Emran, A., Rob, Md. A., & Kabir, Md. H. (2017). Coastline Change and Erosion-Accretion Evolution of the Sandwip Island, Bangladesh: *International Journal of Applied Geospatial Research*, *8*(2), 33–44. https://doi.org/10.4018/IJAGR.2017040103

Goodbred, S. L., & Kuehl, S. A. (2000). Enormous Ganges-Brahmaputra sediment discharge during strengthened early Holocene monsoon. *Geology*, *28*(12), 1083. https://doi.org/10.1130/0091-7613(2000)28%253C1083:EGSDDS%253E2.0.CO;2

Haque, A., Akter, S. A., Pial, M. A. M., Kadir, A., & Ahmed, Z. (2025). Morphological changes and their impact on the resident's livelihood patterns of Char Munshi, lower Meghna estuary, Bangladesh. *Results in Earth Sciences*, *3*, 100073. https://doi.org/10.1016/j.rines.2025.100073

Khalil, I. B., Azad, A., & Madani, A.-U.-Z. (2024). *MORPHOLOGICAL ASSESSMENT OF SANDWIP ISLAND USING GIS AND REMOTE SENSING TECHNOLOGY*.

Khorram, S., Nelson, S. A. C., Van Der Wiele, C. F., & Cakir, H. (2016). Fundamentals of Remote Sensing Imaging and Preliminary Analysis. In J. N. Pelton, S. Madry, & S. Camacho-Lara (Eds.), *Handbook of Satellite Applications* (pp. 1–36). Springer New York. https://doi.org/10.1007/978-1-4614-6423-5_46-3

Munasinghe, D. S. N., Cohen, S., Keellings, D. J., Lakshmi, V., Liu, H., & Nienhuis, J. (n.d.). *GLOBAL RIVER DELTA MORPHOLOGY RESPONSE TO FLUVIAL SEDIMENT CHANGE AND ANTHROPOGENIC STRESS*.

Pal, S., Khatun, S., & Mahato, S. (2022). Charland mapping and analyzing suitability for settlement and agriculture in ganga river within the stretch of West Bengal, India. *Geocarto International*, *37*(25), 9583–9606. https://doi.org/10.1080/10106049.2021.2022012

Rashid, Md. B., Ahsan, K., Majlis, A. B. K., Ahsan, Md. K., & Mahmud, A. (2024). Sedimentation and coastal area management in the human-modified Ganges–Brahmaputra tidal delta plain of Bangladesh. *International Journal of River Basin Management*, *22*(1), 31–43. https://doi.org/10.1080/15715124.2022.2092489

Salter, G., Passalacqua, P., Wright, K., Feil, S., Jensen, D., Simard, M., & Lamb, M. P. (2022). Spatial Patterns of Deltaic Deposition/Erosion Revealed by Streaklines Extracted From Remotely-Sensed Suspended Sediment Concentration. *Geophysical Research Letters*, *49*(11), e2022GL098443. https://doi.org/10.1029/2022GL098443

Sarker, M. H., Thorne, C. R., Aktar, M. N., & Ferdous, Md. R. (2014). Morpho-dynamics of the Brahmaputra–Jamuna River, Bangladesh. *Geomorphology*, *215*, 45–59. https://doi.org/10.1016/j.geomorph.2013.07.025

Syvitski, J. P. M., Kettner, A. J., Overeem, I., Hutton, E. W. H., Hannon, M. T., Brakenridge, G. R., Day, J., Vörösmarty, C., Saito, Y., Giosan, L., & Nicholls, R. J. (2009a). Sinking deltas due to human activities. *Nature Geoscience*, *2*(10), 681–686. https://doi.org/10.1038/ngeo629

Syvitski, J. P. M., Kettner, A. J., Overeem, I., Hutton, E. W. H., Hannon, M. T., Brakenridge, G. R., Day, J., Vörösmarty, C., Saito, Y., Giosan, L., & Nicholls, R. J. (2009b). Sinking deltas due to human activities. *Nature Geoscience*, *2*(10), 681–686. https://doi.org/10.1038/ngeo629

Tarafder, Md. T. A., Neha, M. I., & Rahman, Md. A. (2025). *Dynamic morphological change analysis of Sandwip island at Meghna Estuary using remote sensing and GIS techniques*. 020033. https://doi.org/10.1063/5.0248722

Tessler, Z. D., Vörösmarty, C. J., Grossberg, M., Gladkova, I., Aizenman, H., Syvitski, J. P. M., & Foufoula-Georgiou, E. (2015). Profiling risk and sustainability in coastal deltas of the world. *Science*, *349*(6248), 638–643. https://doi.org/10.1126/science.aab3574

Toa, S. S., & Ali, A. A. B. (2022). A Remote Sensing-Based Approach to Identifying Spatio-Temporal Changes in Coastal Morphology in Bhola District, Bangladesh. *Journal of Engineering Advancements*, 76–90. https://doi.org/10.38032/jea.2022.03.002