

The Role of Wave Dynamics in Shoreline Formation and Erosion along the East Midnapore Coastal Tract, West Bengal, India

Dr. Kartik Chandra Rishi

State Aided College Teacher-1, Department of Geography

Hijli College, Kharagpur, West Bengal, India

rishikartik.88@gmail.com

Abstract: *This study examines the role of wave dynamics in shoreline formation and erosion along the Midnapore coast. Various wave parameters, including wavelength, wave period, wave height, frequency, amplitude, velocity, and energy, were measured across four coastal stations: Dadanpatrabar, Jalda Khoti, New Digha, and Old Digha. The study applies simplified Airy's wave theories and established coastal geomorphic models to understand wave behavior in shallow marine environments. Relationships between wave characteristics and shoreline changes are analyzed. The findings highlight how variations in wave energy, relative depth, and wave approach angle significantly influence sediment transport, shoreline modification, and erosion-accretion processes.*

Keywords: Wave dynamics, sediment transport, shoreline change, East Midnapore coast

I. INTRODUCTION

The analysis of the shoreline is one of the most important parameters for change detection of coastal erosion and deposition, as well as the study of coastal morphodynamics (Armenio, 2019). The coastal shorelines are the interface between land and sea, which changes unsteadily in response to one or more factors, such as morphological, climatic, and geological aspects (Mujabar et al., 2013). The shoreline characteristics depend on the interactions between and among waves, tides, storms, rivers, geotectonic, and physical processes dynamically (Passeri et al. 2015). Sea waves are considered the main source of energy in the coastal areas. This study is very significant to understanding the following objective: (a) to analyze how wave dynamics influence shoreline formation and erosion by examining the processes of wave generation, energy transfer, and sediment transport.

II. METHODS AND TECHNIQUES

There are several parameters of coastal hydraulics which are measured by using an auto dumpy level, current meter, echo-sounder, anemometer, staffs, tapes, etc. These measurements have been conducted at four selected locations, such as Dadanpatrabar, Jalda Khoti, Old Digha, and New Digha, in different time periods. Wave height, wavelength, wave period, wave frequency, wave amplitude, wave velocity, wave steepness, wave energy, and wave depth have been measured by conventional equipment, and these have been calculated with the help of general theories of waves (Table 1). The Digital Shoreline Analysis System (DSAS) is determining the change rate of the shoreline from 1975 to 2022. The shoreline change has been calculated using EPR statistics (Rishi et al., 2023).

III. LOCATION OF THE STUDY AREA

The East Midnapore coastal tract is situated in the Purba Medinipur district of West Bengal, India, extending between 21°36' 35" N and 22°02' 23" N latitudes and 87°22' 48" E and 88°01' 12" E longitudes (Figure 1). This coastal tract includes four CD Blocks: Ramnagar I and II, Contai I, and Deshapran.



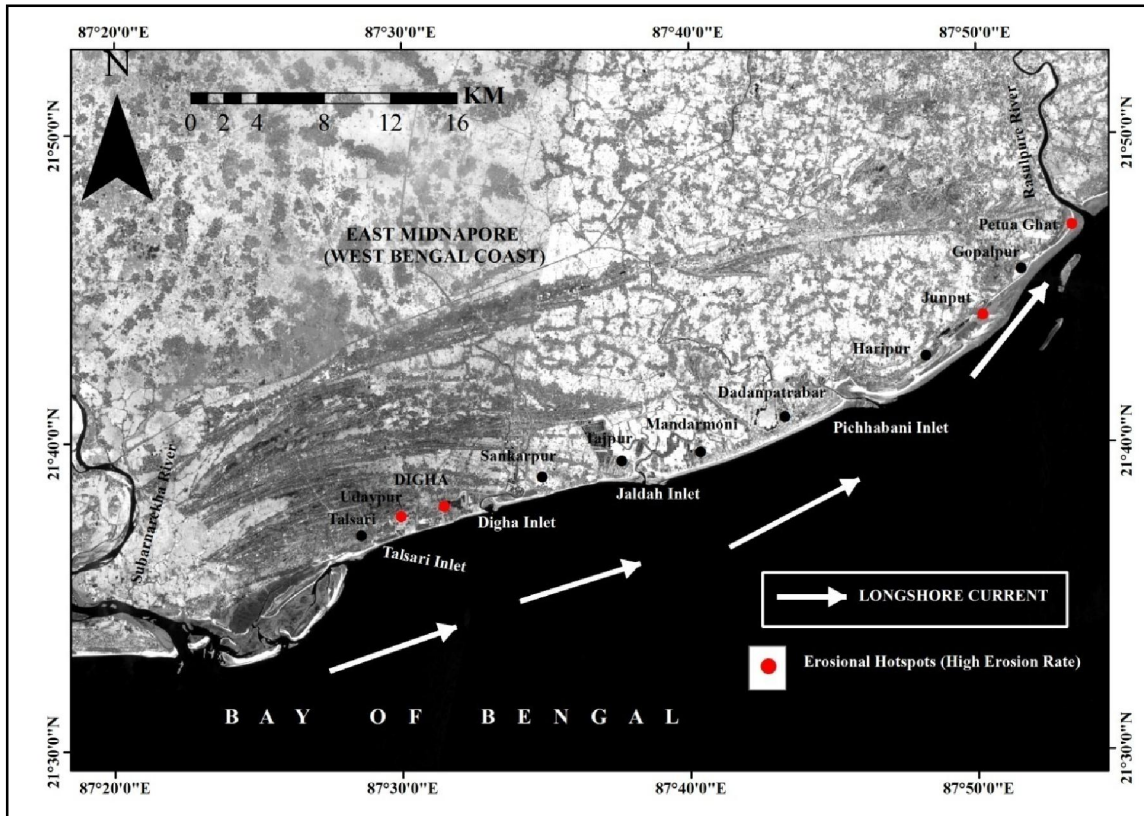


Figure 1: Location of the study area

IV. WAVE PARAMETERS

1. Wave lengths (L)

Wavelength is the horizontal distance between two successive wave crests or troughs. It is measured manually by means of tape. During this measurement, the distances between two consecutive wave crests before breaking in a shallow sea have been taken. Simplified versions of Airy's (1841) equations are used in this study.

$$\text{Wave Length (L)} = T \sqrt{gd}$$

Where, T = Wave period, g = 9.81 ms⁻², d = Water depth

2. Wave periods (T)

The passing time of two consecutive crests or troughs through a fixed point is called the wave period. The measurement of the wave period has been done by means of a stopwatch. The standing at a fixed point of shallow sea ($d / L < 0.05$) recorded the time interval of hitting two consecutive wave crests/troughs.

3. Wave Height (H)

Wave height is defined as the vertical difference between the wave crest and trough. In this study, wave height is measured manually by means of staff, along with taking readings of a trough and subsequent crest at the same station. It is defined in the following equation:

$$H = 0.36 \sqrt{F}$$

Where, H = Wave height, F = Fetch distance



4. Water Density (ρ)

It is the ratio between the unit mass of water and its volume. The density of water has been derived by collecting water samples from the shallow seas of the study area. It is defined in the following equation:

$$\rho = m/v$$

Where, ρ = The Density of water, gm/cm³, m = The Mass of water, v = The Volume of water

5. Wave Frequency (F)

Wave frequencies are the number of waves that pass through a fixed position over a unit period of time. It is the division of one by wave period, which indicates the number of waves that pass through a point; it is measured in waves per second. It is defined in the following equation:

$$F = 1/T$$

Where, F = Wave frequency, T = Wave period

6. Wave Amplitude (A)

Wave amplitude is referred to as half of the wave height. It indicates the vertical difference of a crest or trough from the mean level of water. It is the division of wave height by two. It is expressed in the following general equation:

$$A = H / 2$$

Where, A = Wave amplitude, H = Wave height

7. Wave Approaching Angle (α)

The wave approaching angle is the angle difference between the wave crest and the shoreline. It can be expressed as an angle (α), which indicates the difference between the beach bearing and the wave crest bearing.

8. Wave Velocity (C)

The velocity of a wave is actually the motion of wave energy, which is called kinetic energy. Velocity is proportional to the depth of water. The wave velocity has been measured by a current meter. According to Airy (1841), wave velocity is defined in the following equation:

$$C = \sqrt{gd}$$

Where, C = Wave velocity (m. /sec), g = Gravitational acceleration, d = Water depth

9. Wave Steepness during Breaking

It is defined as the ratio between wave height and wave length during breaking. According to King (1972), wave steepness during breaking is expressed in the following equation:

$$\text{Wave steepness} = H/L$$

Where, H = Wave height, L = Wavelength

10. Wave Energy (E)

The amount of wave energy differs according to its location and time. When a wave is in the deep sea, the kinetic energy is far greater than the potential energy, but as the wave approaches the shallow sea due to a decrease in water depth, the wave height becomes higher, and consequently, the potential energy becomes higher than the kinetic energy; this is known as wave attenuation. According to Airy, wave energy is defined in the following theory:

$$E = 1/8\rho gH^2$$

Where, E = Wave energy, P = Water density, g = Acceleration due to gravity, H = Water height



Table 1: Calculated values of different wave parameters by general wave theories

Sl. No.	Wave Parameters	Dadanpatrabar	Jalda Khoti	New Digha	Old Digha
1.	Wave Length (L)	17m	12.91m	14m	13.5m
2.	Wave Period (T)	7.58"	6.04"	5.33"	7.97"
3.	Wave Height (H)	0.385m	0.569m	0.375m	0.391m
4.	Water Density (ρ)	1.038gm/cm ³	1.038gm/cm ³	1.038gm/cm ³	1.038gm/cm ³
5.	Wave Frequency (F)	0.132	0.237	0.191	0.147
6.	Wave Amplitude (A)	0.193m	0.285m	0.188m	0.196m
7.	Wave approaching angle (α)	16°56'	13°32'	4°52'30"	9°27'
8.	Wave Velocity (C)	3.088m/s	3.233m/s	3.286m/s	3.578m/s
9.	Wave Steepness during breaking	0.039	0.066	0.031	0.034
10.	Wave Energy (E)	0.18866782 Jul/m ²	0.4120989 Jul/m ²	0.17899419 Jul/m ²	0.194594198 Jul/m ²

Source: Calculated by the Author

V. RESULT AND DISCUSSIONS

The East Midnapore coastal tract is classified by five sections, namely high erosion, low erosion, little/stable change, low accretion, and high accretion rate (Rishi et al., 2023). In the study, the total length of coastline is 55.22 km, where high erosion covered 1.50 km of the coastline, followed by low erosion 25.69 km, little change 4.40 km, low accretion 10.93 km, and high accretion 12.70 km. (Figure 2). Comparing the erosion and accretion of five zones, it is seen that the erosion is highest in areas like Udaypur, Old and New Digha, Junput, Bankipur Beach, Baghaput Beach, and accretion is maximum in areas such as Sankarpur, Tajpur, and Mandarmani. In the previous study, it was shown that in the period from 1877 to 1965, the Digha shoreline moved landward by 970m, whereas the mean retreat is 11 m/yr. Therefore, the shoreline retreat is increased within the period from 1965 to 1995 by 525 meters, whereas the average retreat is 17.5 m/yr. The construction of a sea wall by laterite stones, nearly 4.7 km long, is protecting the erosional rate during 1972-1988 in the east-west sectors of Digha sea coast. The sloping face of the sea wall touched the part of the beach plain and protected the bank line behind the long sea wall from open wave meeting (Paul, 2002). Changes in local sea level and storm surge are affected by seasonal variation, which generates large wave heights, and it influences coastal erosion over time. The controlling factors of coastal erosion of the study area are recognized as- (a) strong littoral drift on the fine grained and flat beach bordered with dune in the landward side, (b) loss of sandy materials inland by wind action, (c) possibly of faulting features in the Digha shore-face in recent past (d) the strong tides occur during cyclonic storm and (e) bathymetry measure of the inner continental shelf and orientation of the 'Western Brace' with respect to Digha at its shore-face (Mukherjee et al., 1997).



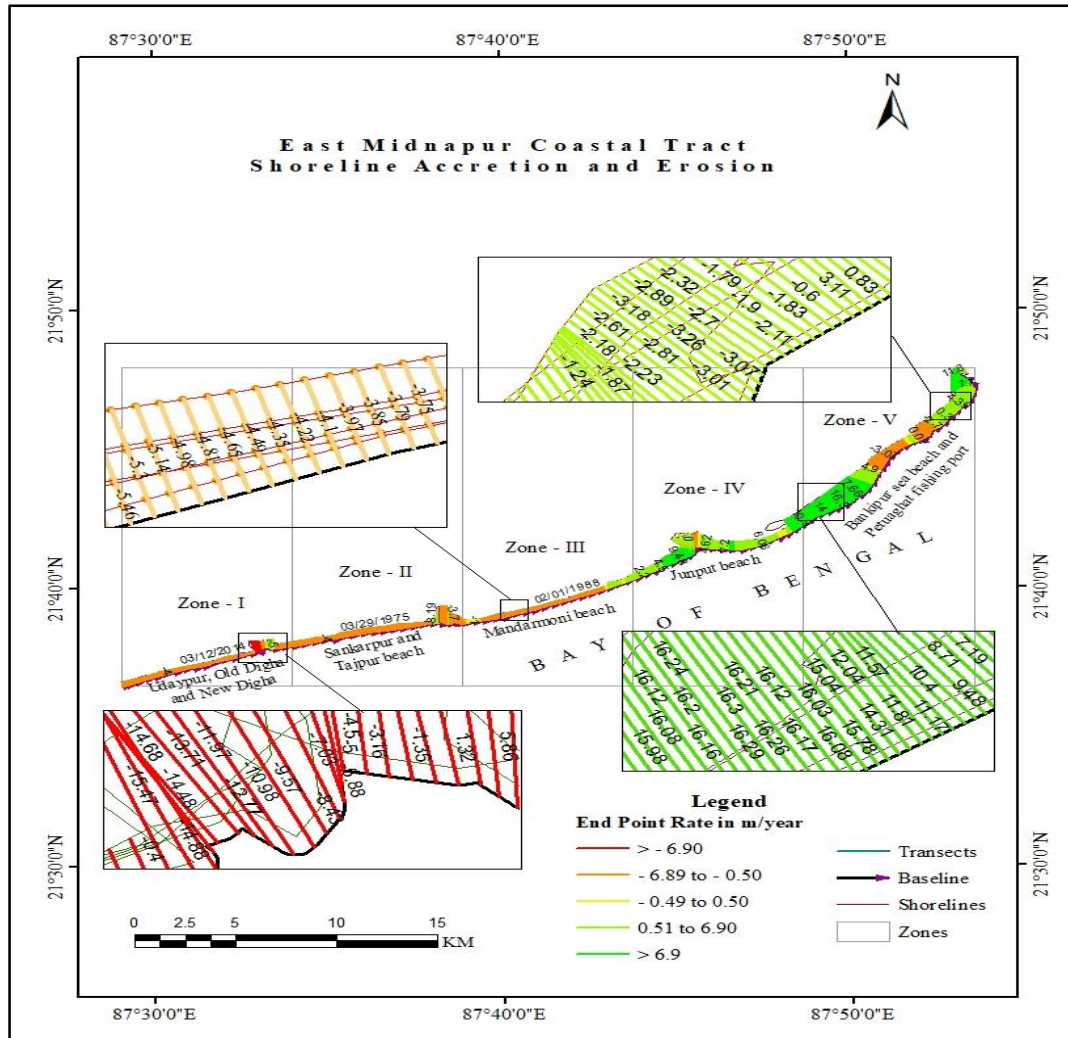


Figure 2: Shoreline accretion and erosion in East Midnapore Coastal Tract using EPR (Rishi et al., 2023)

VI. CONCLUSION

The study reveals that wave dynamics play an essential role in shaping shoreline morphology along the Midnapore coast. Variations in wave parameters such as height, wavelength, and velocity directly influence coastal erosion and deposition processes. Shallow water conditions intensify wave height and energy concentration, leading to increased potential for shoreline erosion. Relative depth and wave steepness are critical in determining breaker types and sediment transport intensity. The wave approach angle significantly controls longshore drift and sediment redistribution along the coast. Differences observed among the four stations indicate spatial variability in hydrodynamic conditions and geomorphic responses. The application of Airy’s wave theory provides a reliable framework for understanding coastal processes. Overall, the findings emphasize the importance of continuous monitoring of wave parameters for effective coastal zone management, erosion control strategies, and sustainable development planning in vulnerable coastal regions.



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