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The relationship between Wave Morphodynamic Indices and Sediment Grain Size along the Puri Coast, Orissa: A Beach stage Models

Debasish Dasmahapatra
State Aided College Teacher, Department of Geography
Egra Sarada Shashi Bhusan College, West Bengal, India
Email – debageo8@gmail.com

Abstract: *The study investigates the relationship between wave morphodynamic indices and sediment grain size along the Puri Coast. Wave and sediment-related datasets were collected from selected locations on the open coast and estuary to evaluate the relation between the two coastal morphodynamics indices. In this paper, we used Airy's wave theory to examine the wave height, length, period, depth, velocity, and wave frequency. Examine the sediment grain analysis; we used the Wentworth method. The results show that the Puri coast revealed that the beach is steep, composed of coarse to medium sand, and is dominated by waves. The prominent beach face is developed by a swash deposit. The Backwash is insignificant as most of the swash water infiltrates through the coarser deposit. Due to the dominance of high-energy waves, the beach is mostly composed of coarse to medium sand. Grain is coarser on the beach face and finer on the dune at the landward margin. The wave is plunging. Now, present-day Puri beach is situated in the intermediate domain on the beach stage model.*

Key Words: *Morphodynamic, Wave, Texture, Grain Size, Puri Beach.*

1. INTRODUCTION:

The coast is the part of the earth's surface where the land, water, and air meet as a zone of mixing or adjustment where terrestrial environments influence marine environments and vice versa. Tidal, aeolian, marine, and glacial processes are all interacting in a narrow region. Terrestrial processes like rivers and glaciers, marine processes like waves, tides, and currents, and atmospheric processes like wind are acting together to give rise to a series of landforms in the coastal region, such as beaches, bars, stamps, etc.; The shape, size, and other attributes of a landform depend on the processes The geomorphology of the coastal region changes with the processes: if the process is wave, the beach will be steep; if the process is tide, the beach will be gentle; if the process is high wind, the beach will be steep. This region is constituted of coarser, medium, and fine sand due to wave dominance. The coarse sand concentration indicated the availability of strong wave energy on the beach face. Now a day's sea level rises gradually. Threatening an increase in storm and flood damage in the low-lying populated area. IPCC 2007 predicted that sea level may rise up to 0.6–1.9 ft (prediction for 2100). As a result of shoreline erosion, which is more common with increasing energy prices, the zone of erosion increases upward if sea level rises, and more and more land will come under the active band of erosion.

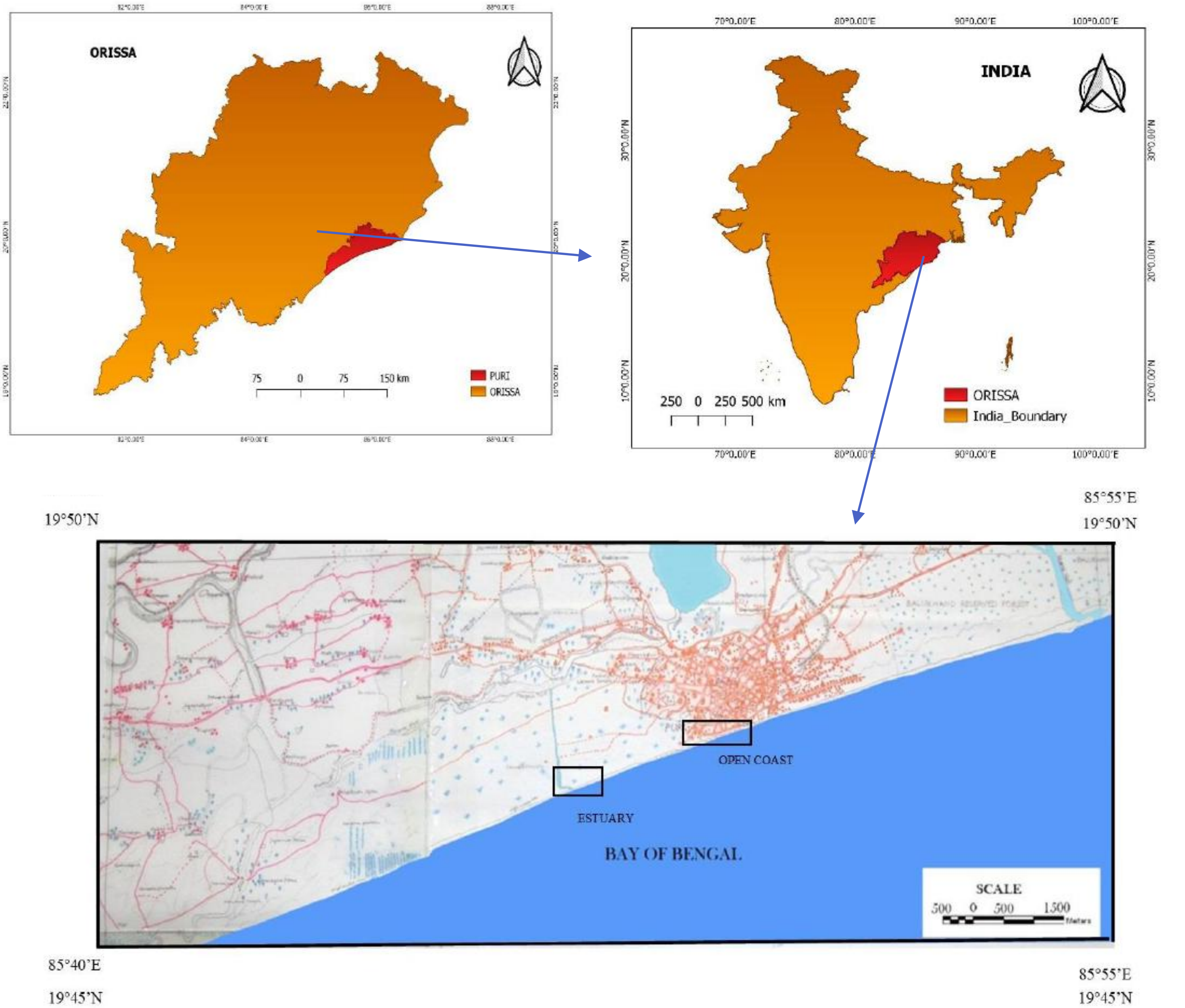
1.1 Literature review:

Angle of wave approach was studied in detail by (2013) with special emphasis on the influence of wave angle on the spit shape; (Bowen, 1978) concentrated on the angle wave approach; Wave frequency and wave lengths were measured and estimated by (Airy, 1845); The wave crest was monitored by Johnston et al. 1948 by establishing wave crest positions, found through attenuating wave lengths along the crest; Chandramohan (1993) studied the wave velocity on an open coast. (Airy, 1845) described the wave energy, which has two forms: kinetic energy and potential energy. The total of these two energies is directly related to the square of the wave height; Chao (1970) has described the way of increasing the wave height; Smith (1976) discussed the development of the height of the giant wave; Languet-Higgins (1970) related wave energy to wave height; King (1972) studied the wave steepness, which is related to the beach gradient; (Haslett, 2016) studied that during the summer period, the low, flat swell waves wave up on the beach berm and the beach face, which form the steep beach profile. (Guza and Bowen, 1975) introduced the surf scaling factor for classifying breaker type; (Chauhan, 1992) discussed the transport of sediment of different sizes in the estuarine channel in connection to the difference in tidal current; Pradhan et al. (2020) have shown the amount of sand transport per unit beach width per unit time.

1.2 Location of the study area:

Puri district is the southernmost district in the province of Orissa. The Puri coast is situated on the northwestern part of the 46'9.32" E.Bay of Bengal. The study area consists of both the open coast and estuarine coast. The open coast extended in147'°07.6 19° 46’56.3 46' 56.3d 19°and’04. 47' 04.6" N and 19° 46' 07.1o 19°46’07.1’’ N latitude. The longitudinal extension of the open coast is 85°47’47.4’’ E to 85°46’08.91’’ E and 85°47’49.2’’ E to 85°46’9.32’’E (Fig 1). The total area of Puri district is 3,051 square kilometers. The total population of the Puri district is 1,502,682, and the population density is 492 sq. km. The sex ratio of the Puri district is 1.032. The literacy rate of the Puri district is 73.86%. The study area generally experiences an "AW" climate (according to Koppen). The average summer temperature is 37°C, and the average winter temperature is 13.9°C. The actual length of the Puri sea beach is 150.4 km. The average wind speed is, during the data collection period, 7.74 km/hour.

Fig 1: location map of study area



1.3 Objectives:

- To monitor the coastal processes and establish a relationship between wave and sediment grain size.
- To understand the distribution of grain size in relation to dominant processing.
- To understand the wave morphodynamic process in the study area.

2. DATABASE AND METHODOLOGY:

Wave properties are measured through different instruments. The data about wave height were collected using staff, dumpy level, tape, etc. Wave frequency had been measured by the use of a ranging rod and stopwatch. How many members of the wave were passing through a fixed point in a unit of time indicates wave frequency. For the measurement of the wave period we took a fixed or reference point was monitored it by a stopwatch. The collected data on wave height, wave period, wave frequency, etc. have been calculated for analyzing the different wave formulas (Table 1):

Table 1: wave morphodynamic indices

Sl no	Indices	Formula	Remarks
1	Wave Height in shallow water	Vertical distance between wave crest and trough.	How much energy a wave can be get depend on the wind velocity and tidal condition
2	Wave length in shallow water	L = $\frac{g+2}{2\pi} \times r$	While the wavelength decreases the wave height increases.
3	Wave velocity in shallow water	C = $\frac{\sqrt[T]{gd}}{T}$	Open coast wave velocity is totally controlled by water depth. But in estuarine environment tidal condition as well as the flow velocity and direction of river are the key factors.
4	Wave frequency in shallow water	f = $\frac{1}{Wave\ Period\ (T)}$	An increase in wave frequency caused a decrease in wave length while the wave speed remained constant.
5	Wave period in shallow water	Time between successive crests to pass through a fixed point	Wave period is inversely proportional to wind speed.

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For sediment, grain size analysis samples were collected from selected parts of every profile in both the open coast and estuarine coast and the sample packets were numbered according to the record book. Beach soil samples were collected for the grain size analysis. From the collected soil samples grain size is analysed using the Wentworth method. Sediment samples were classified with (-1φ, 0φ, 1φ, 2φ, 3φ, 4φ, 5φ and 6φ) several net size. Each category was measured (weight in grams).At first, we calculated the % value of grain size-wise weighted value of each sample following the Wentworth φ distribution scale -1φ,0φ,1φ,2φ,3φ,4φ and 5φ. The grain size φ value is that (depending on Krumbein suggestion) φ=-log2mm. The percentage weight of distributed grain sizes was made cumulative and from the cumulative frequency curve, the 16^{th}, and 50th and 84^{th} percentile for each sample was calculated.

3. RESULT AND DISCUSSION:

3.1 Wave Morphodynamic Indices

The Driving force behind every coastal process is waves. Waveforms when the water surface is disturbed, this disturbance may occur due to wind action, tectonic activity, or Gravitational forces. During such disturbance energy and momentum are transferred to the water mass and transmitted in the direction of the impelling force. This energy influences many coastal processes. So, it is necessary to understand the wave dynamics before any discussion of coastal phenomena. Wave may be described geometrically in terms of their Height (H), Length (L), Amplitude (A), Water depth (d), Frequency (F), and Wave Period (T), This geometric Trio from the ratio's H/L (wave steepness), H/d (Relative Height), d/L (Relative Depth) which are also used to define wave environments. For example, d/L >0.5 denotes deep water, 0.10 to 0.50 Transitional Water, and d/L <0.10 Shallow Water.Due to high energy, it was very difficult to collect wave height related data continuously (Fig 2). In the observation period, we found a maximum average wave height of 1.24m at C1 (open coast) site during peak high tide conditions and the wind speed was 7.56 km/h. Due to high wind speed, a rising tidal condition when steep beach slope wave height was high. The minimum wave height of 0.38m was found at site B2 when the wind speed was 6.17 km/hr. and rising tidal conditions due to the 55m inward location from the river mouth, the impact of sea waves is gradually decreasing, and as a result wave height also decreases. Wind speed and Tidal conditions directly controlled wave height, as the wind speed is high and peak high tide is in action during noon, wave height became position. In the estuarine environment, the impact of waves gradually decreased from the mouth toward the source. Only 55m distance from the river mouth, the variation of wave height is 0.43m in rising tide conditions.

Fig 2: Wave monitoring site

We monitored the wavelength during breaking at 6 sites with different conditions. We measured water depth and wave period at all the sites. With the help of Airy's formula, we calculated the average wavelength during the breaking. After monitoring, we found a maximum wavelength; of 31.87 m at site B2 when the tidal condition is rising. The minimum wavelength of 18.05 m was found at the B1 site when the tidal condition was peak high tide. The highest wave velocity of 3.76 m/sec was found at the B2 site due to estuaries environment and greater water depth, wave velocity was much more than at other sites.

Table 2: Wave related data

NATURE OF COAST	SITE	LOCATION	AVG. WAVE HEIGHT (m)	AVG. WAVE LENGTH (m)	AVG. WAVE PERIOD (sec)	AVG. WAVE DEPTH (m)	AVG. WAVE VELOCITY (m/sec)	AVG. WAVE FREQUENCY /sec
Open Coast	A1	19°47.486N,85°48.924E	0.71	22.85	6.76	1.18	3.39	9
	A2	19°47.473N,85°48.892E	0.85	22.38	6.29	1.3	3.55	9
	A3	19°47.562N,85°48.920E	0.59	24.17	7.34	1.17	3.31	8
Estuary	B1	19°46.868'N,85°47.05'E	0.81	21.45	6.64	1.09	3.27	9
			1.2	18.05	4.89	1.44	3.75	13
Channel mouth	B2	19°46.7'N,85°47.08'E	0.38	31.87	8.51	1.45	3.76	7
			0.84	22.92	6.4	1.31	3.57	10
Open Coast	C1	19°48.132'N,85°49.12'E	1.24	21.52	5.83	1.42	3.72	11

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The measurement was done in a mid-tidal situation when the velocity was maximum lowest wave velocity of 3.27 m/sec was found at the B1 site (Table 2). As the site is located at the mouth of the river Mandala, collision between wave and river water flow slows the wave. Wave velocity is the indicator of wave energy, and the function of a wave depends on its energy. The characteristics of wave velocity totally different in open and estuaries coast. During the observation period, we found that on the open coast, wave velocity is totally controlled by water depth. But in estuaries environment, tidal conditions as well as the flow velocity and direction of the river are the key factors. During the mid-session of high tide, as the wave energy is much greater than the flow movement of the river, the wave velocity is much greater. This impact extends for a distance from the river mouth. As the energy of the wave and the river act in opposite directions, the wave velocity decreased. This situation is very much active at the mouth of the river, but from 55 m inward site from the river mouth (B2 site) wave velocity decreased considerably due (Fig 3,4,5,6).

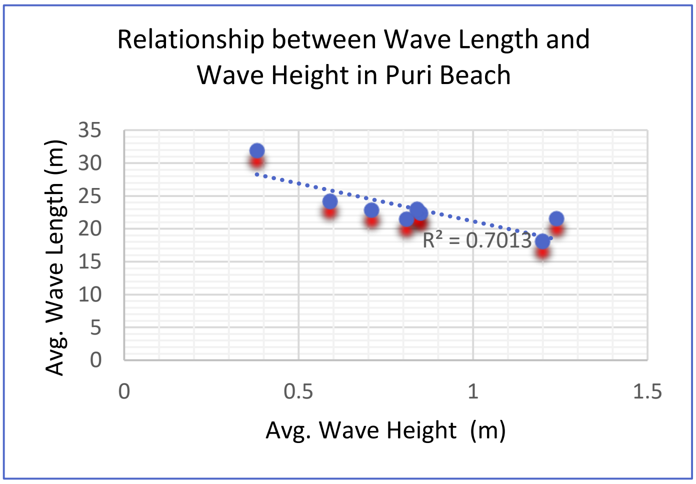

Fig 3: Wave Length and Wave Height

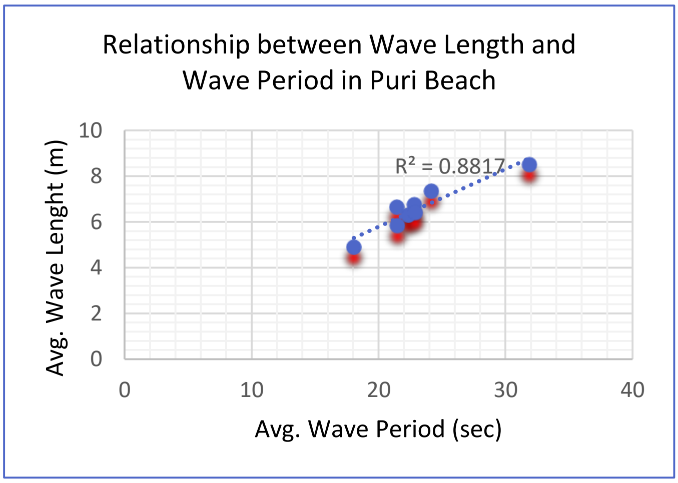

Fig 4: Wave Length and Wave Period

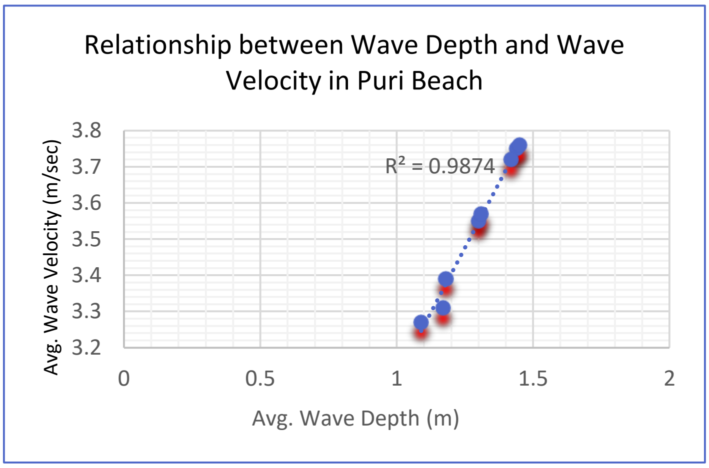

Fig 5: Wave Depth and Wave Velocity

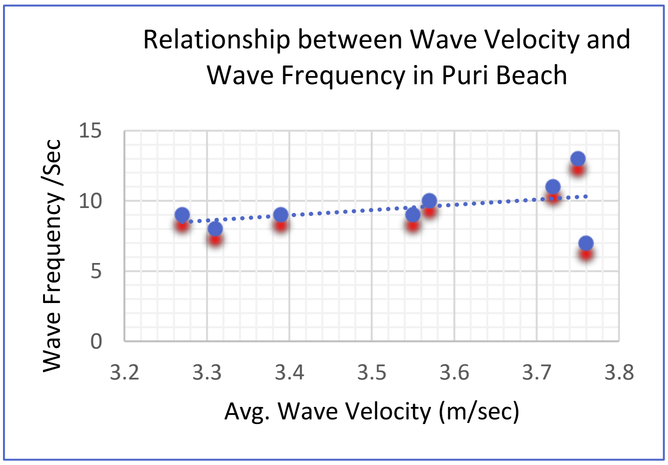

Fig 6: Wave Velocity and Wave Frequency

3.2 Sediment Grain Size

The energy inputs in the coastal system from wave, current, tide, and wind are linked to landforms of the coastal region by formation –transport, sorting, aggregation, stability, of deposition of sediments. Shoreline gradation also depends on this process. Sediments are of two categories one is clastic sediment, formed by rock detrital, and the other type is calcium carbonate, formed by agglomeration shells or skeletons of invertebrates. Clastic and carbonate sediments are also divided into categories, based on their formation method. Cohesion-less sediment has a grain size greater than 0.06mm in solid grain form. Other is cohesive sediment characterized by electrolytic forces, mainly composed of secondary clay minerals.). In our work, we have concentrated on cohesion-less sediment grain size analysis in relation to energy and processes. The Wentworth Grades intervals were classified into six categories Very Coarse sand (-1 to 0φ), Coarse sand (0 to +1φ), Medium sand (+1 to +φ2), Fine sand (+2φ to +3φ), Very Fine sand (+3φ to +4φ), and Coarse Silt (+4φ to +5φ).

The soil samples are collected from six locations (A, B, C, D, E, F) (Fig 7).Sample-1,5,10,17,23 was collected from a dune, sample-2,6,9,11,12,15,16,18,19,22,24 from a runnel, sample-3,7,13,20 from the berm, sample-14,21,26,30 from the free face, sample-4,8 from beach face, sample-25 from cups, sample-29 from horn, sample-27,28 from construction effective zone. This profile shows more concentration of 2φ grade (medium sand) than the other grade. This region is constituted of medium and fine sand due to wave dominance. The beach face is mostly constituted by medium sand.To understand the magnitude of wave energy and wind for the movement of sediments (different grain sizes), we calculate a mean grain size.

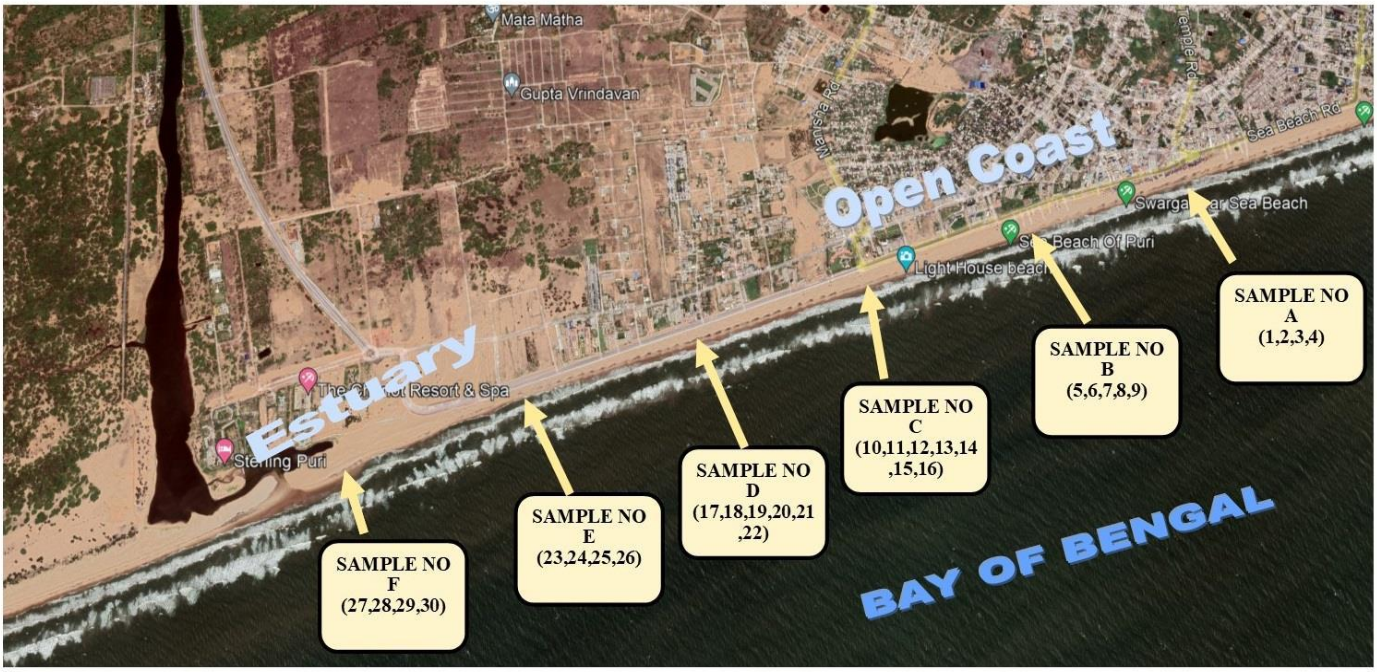

Fig 7: sediment collection site

The percentage weight of distributed grain sizes was made cumulative and from the cumulative frequency curve, the 16th, and 50th and 84th percentile for each sample was calculated. These results were used to calculate mean grain size. Here, we noticed that that >1φ,>2φ mean grain size is concentrated along the shoreline. Medium and coarse sand concentration is high because the magnitude of energy (swash velocity of wave and tide) is high to transport all types of grain size sediments movement from offshore to on shore (Table 2). Back wash velocity is greater than swash velocity, but for the moderate slope, it can only move fine and medium grain size sediments. Wind velocity is low it can only transport fine grain sediments from onshore to dune.

Table 2: Sediment related data

NAME OF THE SITE	SAMPLE NO	LOCATION	SEDIMENT COLLECTION POINT	% VALUE	WENTWORTH GRADES	GRADE VALUE
A	1	19˚47.530'N 85˚48.09'E	Dune	39.86%	medium sand	2φ grade
	2	19˚47.516'N 85˚48.934'E	Runnel	41.56%	coarse sand	1φ grade
	3	19˚47.500'N 85˚48.937E	Berm	57.40%	medium sand	2φ grade
	4	19˚47.496'N 85˚48.938'E	Beach face	62.61%	coarse sand	1φ grade
B	5	19˚47.493'N 85˚48.938'E	Dune	50.71%	medium sand	2φ grade
	6	19˚47.478'N 85˚48.795'E	Runnel	44.13%	coarse sand	1φ grade
	7	19˚47.461'N 85˚48.798E	Berm	62.97%	coarse sand	1φ grade
	8	19˚47.450'N 85˚48.801'E	Beach face	54.15%	coarse sand	1φ grade
	9	19˚47.445'N 85˚48.802'E	Runnel	58.24%	fine sand	3φ grade

C	10	19˚47.449'N 85˚48.657'E	Dune	54.99%	medium sand	2φ grade
	11	19˚47.436'N 85˚48.657'E	Runnel	54.95%	medium sand	2φ grade
	12	19˚47.431'N 85˚48.657'E	Runnel	64.50%	medium sand	2φ grade
	13	19˚47.418'N 85˚48.660'E	Berm	62.34%	medium sand	2φ grade
	14	19˚47.411'N 85˚48.663'E	Free face	54.47%	medium sand	2φ grade
	15	19˚47.405'N 85˚48.666'E	Runnel	51.16%	fine sand	3φ grade
	16	19˚47.399'N 85˚48.666'E	Runnel	76.19%	fine sand	3φ grade
D	17	19˚47.363'N 85˚48.400'E	Dune	53.37%	fine sand	3φ grade
	18	19˚47.348'N 85˚48.401'E	Runnel	58.12%	medium sand	2φ grade
	19	19˚47.336'N 85˚48.407'E	Runnel	65.79%	medium sand	2φ grade
	20	19˚47.330'N 85˚48.410'E	Berm	47.61%	medium sand	2φ grade
	21	19˚47.325'N 85˚48.410'E	Free face	64.14%	fine sand	3φ grade
	22	19˚47.322'N 85˚48.411'E	Runnel	77.51%	fine sand	3φ grade
E	23	19˚47.066'N 85˚47.466'E	Dune	47.16%	medium sand	2φ grade
	24	19˚47.054'N 85˚47.468'E	Runnel	61.07%	medium sand	2φ grade
	25	19˚47.038'N 85˚47.471'E	Cups	60.55%	medium sand	2φ grade
	26	19˚47.035'N 85˚47.474'E	Free face	42.60%	medium sand	2φ grade
F	27	19˚47.034'N 85˚47.326'E	Construction effective land	59.48%	medium sand	2φ grade
	28	19˚47.014'N 85˚47.336'E	Construction effective Runnel	53.58%	medium sand	2φ grade
	29	19˚46.995'N 85˚47.344'E	Horn	64.97%	medium sand	2φ grade
	30	19˚46.992'N 85˚47.345'E	Free face	52.63%	medium sand	2φ grade

Computed by author

3.4 Beach stage model

The "Australian school" of geomorphology has made great studies in providing a viable framework for studying beach and near-shore changes. They have identified a number of distinct morphological "states" or "stages" associated with various wave and tide regimes (wright et al, 1979, 1982a, b, c; short, 1979; wright and short, 1983, 1984). In addition to providing a spatial classification, it is also apparent that the beach may move through a temporal sequence of states to achieve equilibrium.The three main domains mentioned by these researchers are Dissipative, Reflective, and Intermediate (Table 3**).** The dissipative domain extreme is characterized by a flat shoaling slope and a wide surf zone characterized by multiple parallel bars. Infra-gravity waves are present here. The reflective domain extreme is characterized by gradients with no nearshore bars. Leakey or trapped mode gravity edge waves dominate the secondary fluid motions in the narrow breaker zone, leading to the formation of subharmonic or synchronous beach cusps. The intermediate domain incorporates both the elements of reflective and dissipative domains. Intermediate states may arise as a consequence of tidal changes, especially with separate sand and gravel elements.

Table 3 : Beach stage model

Attributes	**Parameter**	**Domain**					
Morph dynamic indices	**Type**	**Reflective**	**Puri Coast (Present Study)**	**Intermediate**	**Puri Coast (Present Study)**	**Dissipative**	**Puri Coast (Present Study)**
	Surf scale	0.1-2.5		2.5-20	(2.71)	20-200	

wave	Number of waves in the surf zone	1		1-3	(1-2)	3	
	Approximate surf zone width in m	<10		10-100	(20.315)	100->1000	
	Breaker types	plunging-collapsing <5.2		plunging and spilling 5.0-0.64	(plunging)	spilling >0.64	
	Swash period (sec)	5-10	(6.58 sec)	10-30		up to 60	
Sediment	Common grade material size	course sand, grit gravel and boulders <0	course sand <0	Medium sand 0 - +2	Medium sand 0 - +2	Silt to fine sand >+2	
Sediment transport	Dominant vectors	Along shore		(Grain size Mixed and beach stage dependent)	(Grain size Mixed and beach stage dependent)	On shore - off shore	

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4. CONCLUSION:

The process at Puri coast revealed that the beach is steep being composed of coarse to medium sand, bring dominated by waves. The prominent beach face is developed by a swash deposit. The backwash is insignificant as most of the swash water infiltrates through the coarser deposit. Shore normal current is the most dominant. The angle of the wave approach is very less. Summer swell wave is responsible for the development of berms and steep beach profile. Due to the dominance of high-energy waves, the beach is mostly composed of coarser to medium sand. On the beach face grain are coarser, on a dune at the landward margin grain is relatively finer. Wave break is a plunging domain. One to two waves are generally present in the surf zone which is almost 20m in width. The energy brought by the wave is distributed over a larger area, so, energy concentration is less. The beach gradient varies from 1° to 3°. It is not rational to establish a concrete conclusion based on such a limited period of study. It may be understood that the beach is in the intermediate domain.

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