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Coastal Vulnerability Assessment of Kanthi Coast, India by the Geospatial Technology

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ABSTRACT

Since ancient times, most of the world's civilization flourished along the banks of rivers and the coastal region. So the coastal region plays a vital role for human economic activities as well as their livelihood. The Kanthi coast, the northernmost part of the North Circus coast of India stretches in West Bengal and northern Odisha. The 45 km stretched coast land is associated with a dense population and faces the tropical cyclone emerging from the Bay of Bengal. The prime objective of the paper is to assess the coastal vulnerability of the study area. With the help of several indicators, viz. shoreline change rate, rate of sea level change, slope of the beach, wave height, tidal range, regional elevation, geomorphic features, sediment properties, coastal regulation zone (CRZ) violation ratio, the research work assess the Coastal Vulnerability Zone (CVZ) of the Kanthi Coastal region. The weightage sum method and Coastal Vulnerability Index (CVI) are being used. From this research work, it has been revealed that the western segment especially, Digha and Shankarpur are experiencing a high vulnerability situation.

INTRODUCTION

The East coast of India is dynamic. The geomorphology of the east coast depends mainly on the landforms and various processes acting on it (Kar, 2018). Tremendous population and developmental pressures have been building in the coastal areas for the last four decades (Kumar et al., 2010). The highly-productive Coastal Zone, intermediate between land and sea, is very vulnerable to coastal hazards because of its dynamic nature (Hossain et al., 2022). Many Asian regions also experience these effects, and in recent years, climate-related disasters have also become prominent in these areas (Krampe and Mobjork, 2018; Dulal, 2019). East and Southeast Asia are at the top of the list of the regions affected (Thomas and Lopez, 2015) and India is one of them. Thus, the study of coastal vulnerability assessment and suitable management according to the problem is vital for the present and future.

Most coastal environments around the world are experiencing the effects of climate change (Nicholls et al., 2018). The coast serves as an interface for three major natural systems on the earth's surface (i.e., the atmosphere, land, and hydrosphere) and provides several ecosystem services that are currently stressed due to several natural and anthropogenic processes such as climate change (Mahapatra et al., 2013). Coastal vulnerability is a spatial concept that can contribute to decision-making processes in managing the coast (Dian et al., 2022). In 1990, prolonged research work was conducted by Gornitz on the east coast of the United States to assess the coastal vulnerability based on sea-level rise. Thieler and Hammer-Klose (1999) assessed the vulnerability of the coastal vulnerability of the U.S. Atlantic coast. Relative sea-level rise rate, shoreline change rate, mean tidal range, mean wave height coastal slope, and geomorphology are used as an indicator to assess the grade of vulnerability.

Belperio et al. (2001) used regional elevation, exposure, aspect, and slope as the physical parameters for assessing the coastal vulnerability due to sea-level rise. Dominey-Howes and Papathoma (2003) employed a new tsunami vulnerability assessment method to assess building vulnerability (BV) at the Gulf of Corinth, Greece. Threat from the tsunami at the coastal area is prominent concerning the matter of the said assessment. Pendleton, Thieler, and Jeffress (2005) considered both geomorphological variables (shoreline-change rate, coastal geomorphology, coastal slope) and physical process variables (sea-level change rate, mean significant wave height, mean tidal range) to design the coastal vulnerability of Golden Gate National Recreation area through the coastal vulnerability index (CVI). Based on physical aspects viz. sea wave, tide, coastline displacement, and elevation, Rajawat et al. sketched the hazard line along the Indian Coast in 2006.

Hegde and Reju (2007) developed the modified coastal vulnerability index (CVI) based on geomorphology, regional coastal slope, shoreline change rates, and population. In 2010, T. Srinivasa Kumar et al. assessed the coastal vulnerability along the Odisha coast through the CVI. Shoreline change rate, sea-level change rate, coastal slope, wave height, tidal range, regional elevation, geomorphology, and tsunami arrival height are used to measure the risk rating. The said research work is used fifteen prominent variables to assess the vulnerability along the Kanthi coast.

Earlier time Kanthi was known as Kendua. The total length of this coast is about 45 km. This coastal region is stretched from the mouth of the Subarnarekha River in the west and the mouth of the Rasulpur River in the east. Orissa coast and Hijili Tidal Canal exists in the north and the Bay of Bengal is in the southern limit of this region. Kanthi Coast is associated with seven beaches, viz. Junput Beach, Shoula Beach, Mandarbani Beach, Tajpur Beach, Shankarpur Beach, Digha Beach, and Talsari Beach from east to west. These coastal areas are also prone to environmental hazards such as erosion and sedimentation processes (Solihuddin et al., 2019; Willemsen et al., 2019). Studies have shown significant changes of coastline in the last decade (Purbani et al., 2019). Coastal zones are an essential part of maintaining sustainability in the world (Noor et al., 2022). Vulnerable coastlines have a low coastal elevation, abrasive sediment, high tide energy, and a greater chance of experiencing storms, such as cyclones and coastal erosion (Guillard-Gonçalves and Zêzere, 2018; Noor et al., 2022). The dense population in the coastal area and the variety of activities make the coastal as an important area, but vulnerable due to natural processes and human activities (Zikra and Suntoyo, 2015; Ningsih et al., 2020). The coastal area is also a strategic area for development as it provides many resources for human livelihoods such as agriculture, fishpond, captured fisheries, mining, and other resource extraction (Solihuddin et al., 2019).

Coastal areas are very important for human existence. People practice their economic activities to secure their livelihood. The main objective of the said paper is the assessment of the vulnerable zone along the Kanthi coast.

MATERIALS AND METHODS

Data and Material

Vulnerability may be defined as an internal risk factor of the subject or system that is exposed to a hazard and corresponds to its intrinsic predisposition to be affected, or to be susceptible to damage (Kumar et al., 2010). The Present research is based on both primary and secondary data.

Table 1. Data Used for Coastal Vulnerability Analysis

No.	Parameter	Data	Resolution	Period
1	Shoreline Change Rate (m/y	LANDSAT MSS	57m	1973
		LISS III	30m	2008 to 2019
2	Sea Level Change Rate (mm/y)	GLOSS data	-	1900 - 2020
3	Coastal Slope/Beach Slope	Field Survey	Beach wise	2016-19
4	Wave Height (m)	Field Survey	Beach wise	2016-19
5	Tidal Range (m)	Kolkata Port Trust	-	2016 - 19
6	Regional Elevation (m)	Google Earth (DEM Generation)	175m	2016
7	Geomorphological features	Field Survey	Beach wise	2016-19
8	Runnel	Field Survey	Beach wise	2016-19

9	Sand Dune	Field Survey	Beach wise	2016-19
10	Tsunami Run-up	Numerical model (Smart et al. 2015)	Beach wise	-
11	Sediment Grain Diameter of Beach (mm)	Field Survey	Beach wise	2016-19
12	Sorting of Beach Sediment (ϕ)	Field Survey	Beach wise	2016-19
13	CRZ (in % of Violation)	LANDSAT MSS LISS III	57m 30m	1973 2008 to 2019
14	Crab Habitat Density (in No. of Habitat/m^2)	Field Survey	Beach wise	2016-19
15	Inlet Migration Rate (m/y)	LANDSAT MSS LISS III	57m 30m	1973 2008 to 2019

All of these parameters are very dynamic in nature. Data that has been used in the said study, derives from the above-mentioned source (Table 1). Remote sensing and GIS tools, numerical models, and field surveys are used.

Vulnerability Assessment Methods (Kumar et al., 2010)

The equation of the coastal vulnerability index (CVI) is the integration of all ratings of those variables into a single indicator. If the numerical of the coastal vulnerability index (CVI) is assigned a risk, then the coastal vulnerability index (CVI) is calculated as the state root of the product of the ranked variables divided by the total number of variables.

$$CVI = \sqrt{\frac{(a*b*c*d*e*f*g*h*i*j*k*l*m*n*o)}{15}}$$

a = Risk Rating Assigned to Shoreline Change Rate
b = Risk Rating Assigned to Sea-level Change Rate
c = Risk Rating Assigned to Coastal Beach Slope
d = Risk Rating Assigned to Wave Height
e = Risk Rating Assigned to Tidal Change
f = Risk Rating Assigned to Regional Elevation
g = Risk Rating Assigned to Geomorphic Features
h = Risk Rating Assigned to Runnel
i = Risk Rating Assigned to Sand Dune
j = Risk Rating Assigned to Tsunami Run-up
k = Risk Rating Assigned to Mean Grain Size
l = Risk Rating Assigned to Sorting
m = Risk Rating Assigned to CRZ Violation
n = Risk Rating Assigned to Crab Habitat Density
o = Risk Rating Assigned to Inlet Migration

RESULTS AND DISCUSSION

Parameters of Coastal Vulnerability Assessment of Kanthi Coast

Most of the population has been settled along the coastline. The different type of parameter of the index helps in the estimation of the vulnerability studies (Anfuso et al., 2009; Boateng, 2012; Mahapatra et al., 2015; Mahapatra et al., 2015; Barman et al., 2016; Demirkesen et al., 2017; Felsenstein et al., 2017; Paul et al., 2020). The coastal region now has various type of problems which influences to coast-associated landforms and habitat also. The present study, therefore, is an attempt to develop a coastal vulnerability index (CVI) (Kumar et al., 2010), for the Kanthi Coastal Beach region. Several parameters, viz. shoreline change rate (meter/year), sea-level change rate (mm/y), beach slope (in degree), wave height (meter), tidal range (m), regional elevation, coast associated geomorphological features, tsunami run-up (m), runnel, dune, beach grain size (mm), Sorting, % of CRZ violation, Crab Habitat density per sq meter and Inlet migration (m/y) are quantified to analysis the vulnerable zone of Kanthi Coastal region.

1. Shoreline Change Rate (m/y)

Coastal shorelines are always subjected to changes due to coastal processes, which are controlled by wave characteristics and the resultant near-shore circulation, sediment characteristics, beach form, etc (Kumar et al., 2010). The balance between accretion and degradation is pronounced by the shoreline change. Therefore, from the shoreline change ratio, the future of the coast is measured.

End Point Rate (EPR)

The endpoint rate (EPR) is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline (Parthasarathy et al., 2018). The prominent advantage of end point rate (EPR) is the computation of the shoreline changes between two shoreline dates. The magnitude of shoreline change is not possible to measure that is the basic problem of the said computation.

Table 2. End Shoreline Change Rate in meter/year (Base Year 1973) of Kanthi Coast

Beach	Junput	Shoula	Mandarbani	Tajpur	Shankarpur	Digha	Talsari
Shoreline change meter/year	2.867	8.076	-1.499	-3.259	-2.251	-3.934	-4.626
Remark	Accretion	Accretion	Erosion	Erosion	Erosion	Erosion	Erosion
Vulnerability	Very Low	Very Low	High	Very High	Very High	Very High	Very High
Median	2.67	9.13	-1.64	-3.19	-3.07	-2.53	-1.99
Mode	4	11	-4.4	-1.07	-3.21	-2.42	1.09
SD	5.06	4.01	3.15	1.83	3.36	4.33	13.66

Source: Researcher’s Computation.

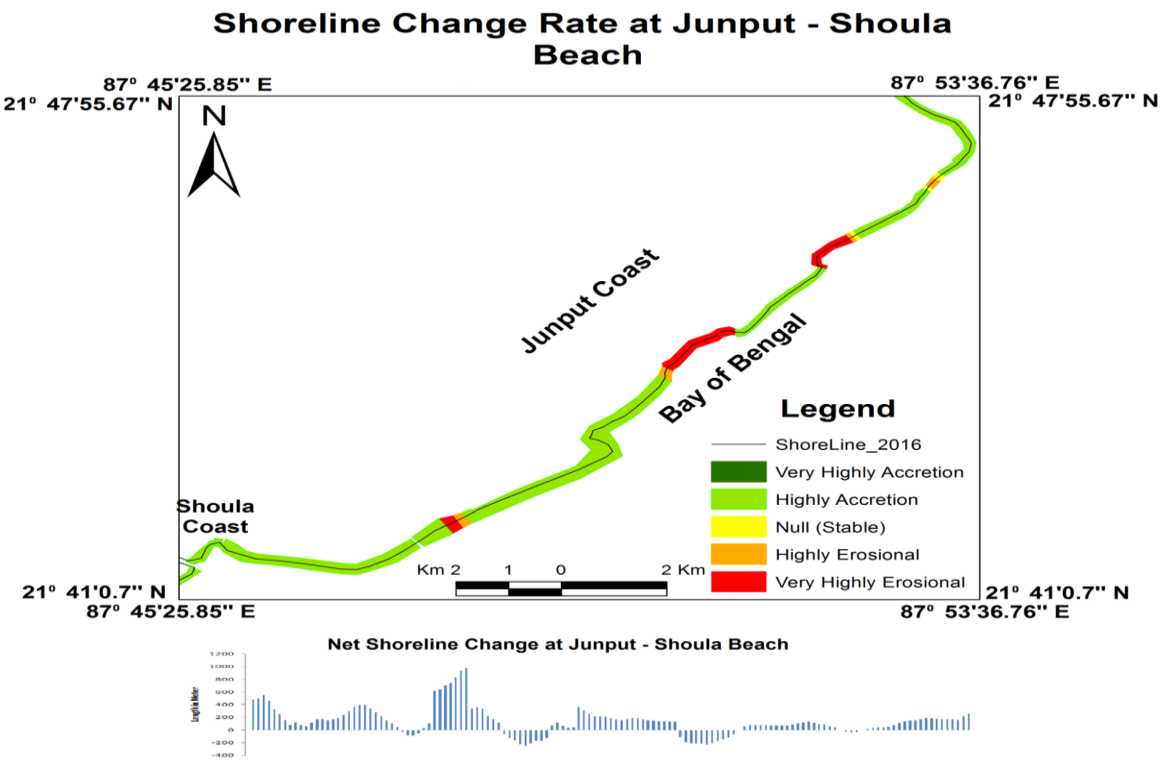

Figure 1. Shoreline Change Rate at Junput – Shoula Beach

From the coastal vulnerability point of view, coasts subjected to accretion will be considered as less vulnerable areas as they move toward the ocean and result in the addition of land areas, whereas areas of coastal erosion will be considered as more vulnerable because of the resultant loss of private and public property and important natural habitats such as beaches, dunes, and marshes (Kumar et al., 2010).

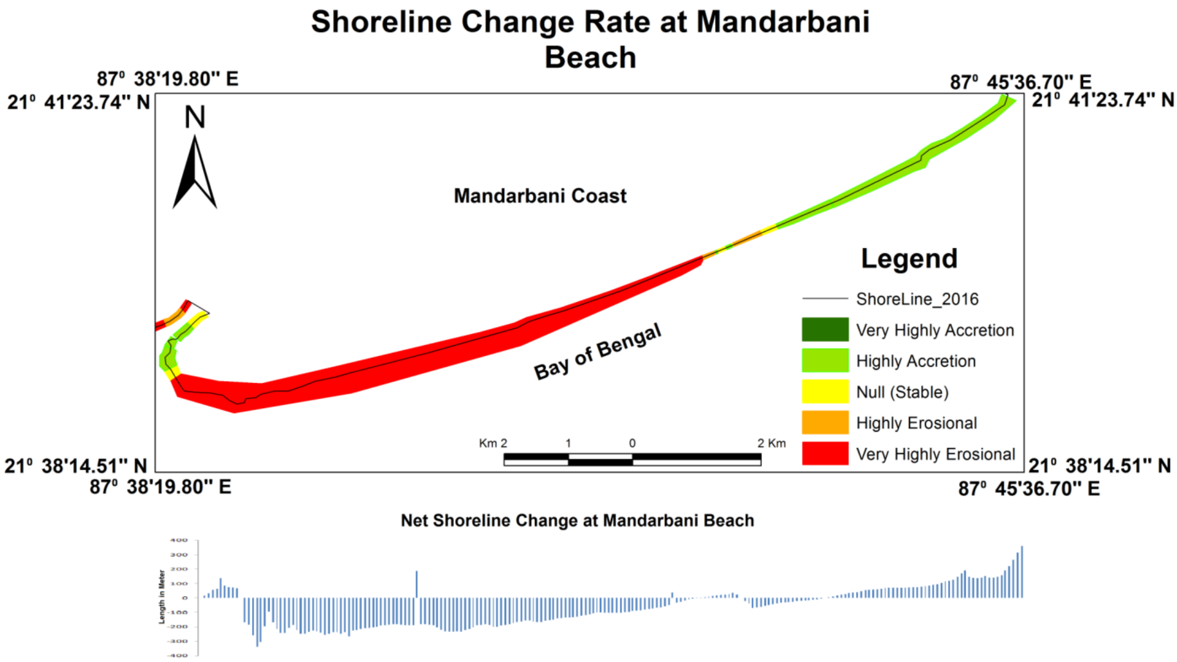

Figure 2. Shoreline Change Rate at Mandarbani Beach

Through, the analysis of shoreline change, it has been revealed that Junput (2.867 m/y) and Shoula (8.076 m/y) are experienced accretion (Table 2, Figure 1) and Mandarbani (-1.499 m/y), Tajpur (-3.259 m/y), Shankarpur (-2.251 m/y), Digha (-3.934 m/y) and Talsari (-4.626 m/y) is characterized as an erosional beach (Figure 2, 3, 4, and 5). Due to longshore depositional work at Junput is become a depositional coastal beach and Shoula also become an accretion coast due to depositional work by the Kanthi and Mirzapur coastal tidal inlet.

Net Shoreline Movement (NSM)

The Net Shoreline Movement (NSM) reports a distance, not a rate. The net shoreline movement (NSM) is associated with the dates of only two shorelines (Parthasarathy et al., 2018). It measures the distance between the oldest (1973) and youngest (2016) shoreline.

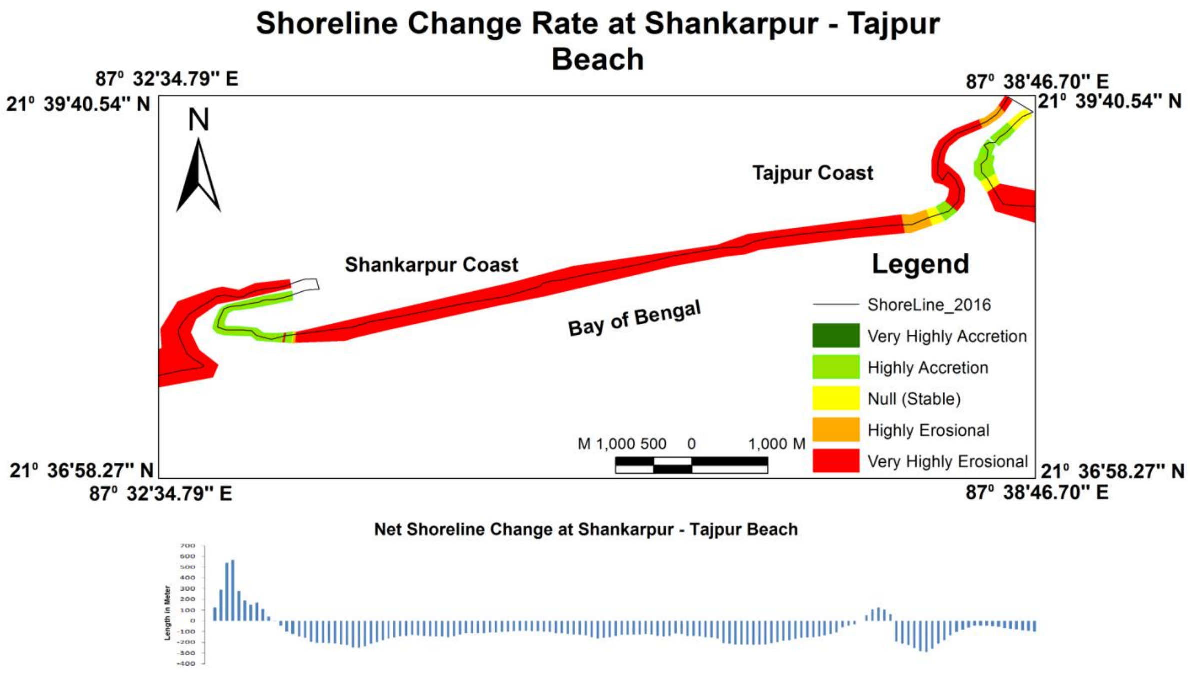

Figure 3. Shoreline Change Rate at Shankarpur – Tajpur Beach

Table 3. Net Shoreline Movement in meter (Base Year 1973) of Kanthi Coast

No.	Coast	Net Shoreline Movement in Meter (Base Year 1973)	Remark
1	Junput	+312.37	Highly Accretion
2	Shoula	+7.75	Null
3	Mandarbani	+94.96	Moderately Accretion
4	Tajpur	-160.00	Highly Erosional
5	Shankarpur	-131.85	Highly Erosional
6	Digha	-237.12	Very Highly Erosional
7	Talsari	-247.48	Very Highly Erosional

Source: Researcher's Computation

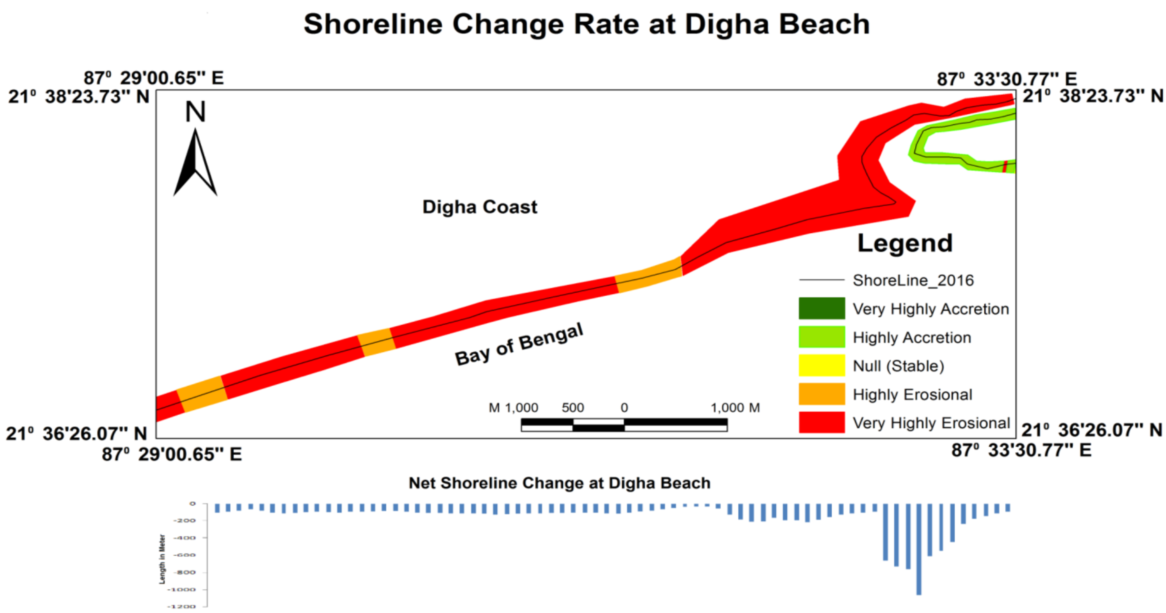

Figure 4. Shoreline Change Rate at Digha Beach

From the above the computation, it has been revealed that Junput (+312.37 m), Shoula (+7.75 m), and Mandarbani (+94.96 m) are experienced accretion and Tajpur (-160.00 m), Shankarpur (-131.85 m), Digha (-237.12 m) and Talsari (-247.48 m) is faced the erosional work (Table 3).

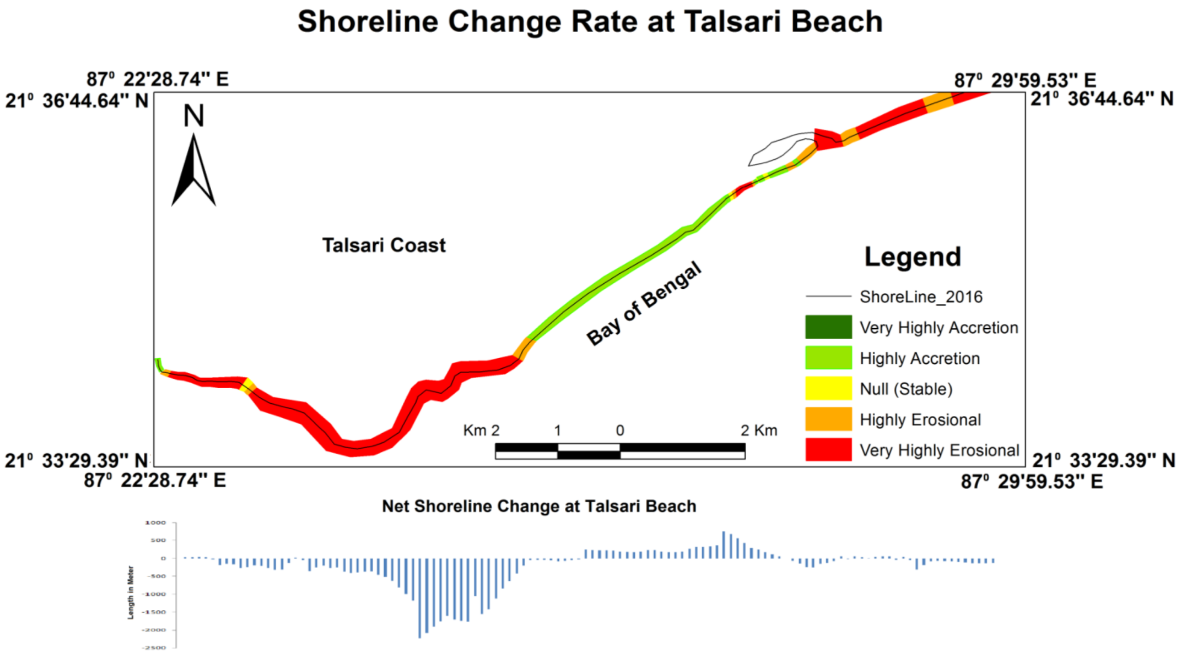

Figure 5. Shoreline Change Rate at Talsari Beach

Shoreline Change Envelope (SCE)

The Shoreline Change Envelope (SCE) represents the shoreline movement against the base shoreline. To measure the SCE, the number of year's shoreline data has been used. Coastal stability is reported by the computation of the shoreline change envelope.

Table 4. Shoreline Change Envelope in meter (Base Year 1973) of Kanthi Coast

No.	Coast	Shoreline Change Envelope in Meter (Base Year 1973)	Remark
1	Junput	474.517336	Highly Stable
2	Shoula	789.4897455	Very High Stable
3	Mandarbani	170.1748146	Stable
4	Tajpur	191.5491497	Moderately Instable
5	Shankarpur	193.5122348	Moderately Instable
6	Digha	231.5614861	Highly Unstable
7	Talsari	412.25458	Highly Unstable

Source: Researcher's Computation

From the research work, it has been revealed that Junput (474.52 m) to Mandarbani (170.18 m) is considered as a sustainable coast (Table 4). Tajpur (191.55 m) to Talsari (412.26 m) of Kanthi coast is over whamming to instability.

2. Sea Level Change Rate (mm/y)

The Mean Sea level is termed as the height of the average water level with in respect to the local benchmark. Sea-level rise threatens coastal ecosystems and settlements, and a number of approaches have been adopted to assess the vulnerability of different coasts (Nicholls et al., 2007 & 2008; Mujabar et al., 2013). Sea-level rise is an important consequence of climate change, both for societies and the environment (Kumar et al., 2010). Since geological periods, the sea level of the eastern coastal plain is ever-changing. The change in mean sea level is known as relative sea level change which is measured by tidal gauges. The base tidal station is Sagar Island, West Bengal, 30 km distance from the Kanthi coast.

According to Kumar et al. (2010) from GLOSS data of Vishakhapatnam station (Figure 7) and tidal gauge data of Sagar tidal station, it has been revealed that the Kanthi coast is facing medium to high risk with respect to sea-level change (According to Hazra et al., 2001 3.14mm/y). From the coastal vulnerability point of view, the coast subjected to a high rate of sea-level rise is considered as a highly vulnerable area and vice versa (Kumar et al., 2010).

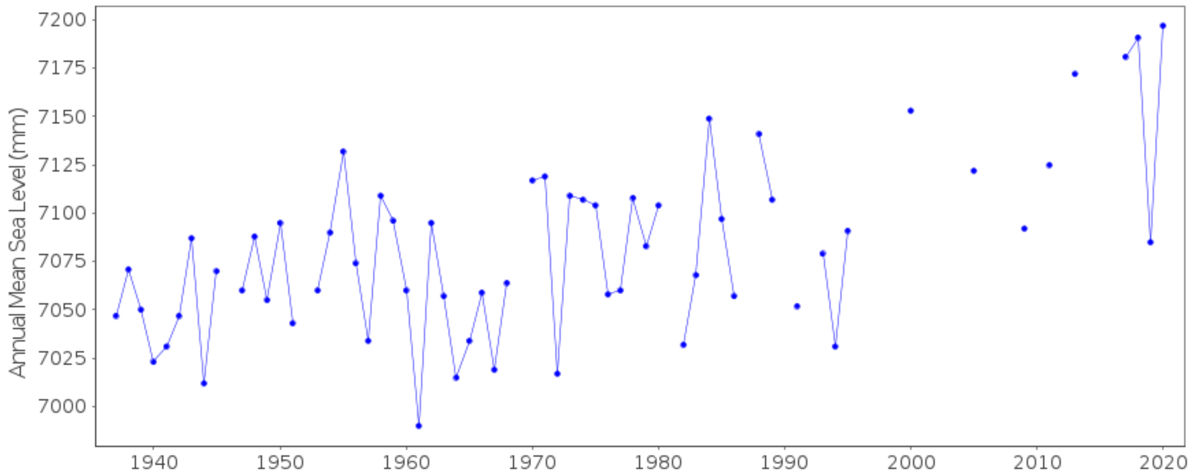

Figure 6. Sea Level Rise, Vishakhapatnam (GLOSS Station Code 35

3. Coastal Slope (Beach Slope)

The nearshore or coastal slope could be defined as the steepness or cross-shore gradient of the subaqueous profile, or the ratio of the gradient of two points on the nearshore zone perpendicular to the shoreline (Elkhateeb et al., 2018; Athanasiou et al., 2019). The Coastal slope is resisting devastating flood and tsunami situations, the coastal slope plays an important role. It is a relevant coastal variable that influences the morphological, hydrodynamic, and coastal processes such as the rate of sedimentation, sediment size distribution, wave characteristics, flooding, loss of land, and inundation of low-lying plains (Elkhateeb et al., 2018; Athanasiou et al., 2019). Coastal Slope is the ratio of change of vertical distance per unit horizontal displacement. The coastal inundated situation is fully influenced by the steepness of the coastal slope. If the slope is steep then it can resist the land from inundation. The coastal slope has measured the steepness of the beach cross profile. The intensity of waves is the most important factor in the susceptibility of tsunamis and coastal hazards. If the slope of the coastal region is gentle, it refers to the great penetration of seawater but the steep slope refers to the less penetration of seawater. Therefore, according to Kumar et al. (2010), the gently sloping beach is considered as a vulnerable zone.

Table 5. Beach Slope of Kanthi Coast

Coast	Beach Slope	Remark (Vulnerability)
Junput	$0^{o}48'07.43''$	Very High
Shoula	$1^{o}03'0.55''$	Very High
Mandarbani	$1^{o}12'44.99''$	Very High
Tajpur	$2^{o}01'46.76''$	Moderate
Shankarpur	$2^{o}51'29.72''$	Very Low
Digha	$1^{o}05'18.45''$	Very High
Talsari	$1^{o}11'36.47''$	Very High

Source: Field Survey (2016-19)

The coastal slope is an important component in determining how vulnerable a coastal region is to inundation from severe storms and tsunamis (Yadav et al., 2022). According to the CVI model of Kumar et al. (2010), except Shankarpur ($2^{o}51'29.72''$), the rest of all beaches of Kanthi coast is considered as a low-risk zone from the subject to beach slope (Table 5).

4. Wave Height

The vertical difference between the crest and trough is known as the height of the wave. The vulnerability study is important to spread cautiousness among people and to resist this type of hazardous situation. The height of the wave depends on the velocity of the wind. Wave height is the positive indicator of wave energy influx towards the sea. The wave energy increases as the square of the wave height. This increased wave energy is the main cause of the mobilization and transportation of beach materials by waves. Thus, high wave height is the cause of degradation and low wave height is the cause of the accretion.

Table 6. Wave Height of Kanthi Coast

Coast	Wave Height (m)	Remark (Vulnerability)
Junput	0.11	Very Low
Shoula	0.105	Very Low
Mandarbani	0.18	Very Low
Tajpur	0.47	Moderate
Shankarpur	0.189	Very Low
Digha	0.755	Very High
Talsari	0.235	Low

Source: Field Survey (2016-19)

Based on wave height, at Junput (0.11 m), Shoula (0.105 m), Mandarbani (0.18), Shankarpur (0.189 m), and Talsari (0.235 m) are characterized as a low-risk zone as per the above computation (Table 6). Digha (0.755 m) is considered as a very high-risk zone due to high wave height, in comparison to other beaches of the Kanthi coast.

5. Tidal Range

The tidal range is the difference in sea level between high tide and low tide. In general, tidal range considers to the vertical distance between high and low water levels. The tidal range is linked to both permanent and episodic inundation hazards (Kumar et al., 2010). The tidal range occurs the tidal current which is quietly vulnerable for the coast. Therefore, the large tidal wave is vulnerable to the coast and vice-versa. The maximum tidal range at the Kanthi coast is above 4.5 meters. Therefore, the beaches of the Kanthi coast are considered as a highly vulnerable zone.

6. Regional Elevation

Vertical extension refers to the Regional Elevation of an area from mean sea level. With the help of the Google Earth Pro Digital Elevation Model (DEM) is created to measure the regional elevation of the study area. DEM is used to extract the elevation profile of any point and in the preparation of contour maps (Pandey and Shukla April 2018). From the coastal vulnerability point of view, coastal regions having high elevation will be considered as less vulnerable areas because they provide more resistance for inundation against the rising sea level, tsunami run-up, and storm surge (Kumar et al., 2010). Usually, those coastal regions having high elevation are considered as low vulnerable coastal zones and vice-versa.

Table 7. Regional Elevation of Kanthi Coastal Beach

Coast	Regional Elevation (m)	Remark (Vulnerability)
Junput	7.61	Moderate
Shoula	5.03	Very High
Mandarbani	5.43	Very High
Tajpur	7.70	Moderate
Shankarpur	7.49	Moderate
Digha	9.51	Very Low
Talsari	6.29	High

Source: Field Survey (2016-19)

It has been observed that the range of the Kanthi coast is 5 to 10 meters. It has been revealed that Shoula (5.03 m) and Mandarbani (5.43 m) are reported as the very high-risk zones of the Kanthi coast in comparison to other beaches (Table 7).

7. Geomorphological Features

The coastal environment is the basic concern of coastal geomorphology. The rise of sea level will restructure the coastal zones. Tidal bedforms, intertidal flats, salt marshes, shingle banks, dunes, cliffs, and coastal lowlands are affected by this inundated situation. This sea level rise and changes in the condition of waves will bring an adverse effect on living organisms in this area and their habitats. Coastal geomorphology is the resultant features of various coastal processes. Therefore, based on beach-associated landform vulnerability is being assessed.

Table 8. Geomorphic features of Kanthi Coast

Coast	Geomorphic Features	Average Rating	Remark (Vulnerability)
Junput	VC, IC, EC, SB, D, S, MF	2.429	Moderate
Shoula	IC, EC, SB	2.000	Very Low
Mandarbani	SB	3	Very High
Tajpur	SB, D	3	Very High
Shankarpur	SB	3	Very High
Digha	SB	3	Very High
Talsari	IC, EC, VC, D, S, MF	2.333	Low

Source: Field Survey and Observation (2016-19)

Note: VC – Vegetated Coast (M), EC – Estuaries Coast (M), SB – Sandy Beach (H), IC – Inundated Coast (L), D – Delta (H), S – Spit (H), MF – Mud Flat (H).
Risk Rating: Low (L) – 1, Medium (M) – 2, High (H) – 3. (After Kumar et al. 2010)

During the Field Survey, it was observed that the Shoula, Talsari, and Junput coasts are treated as very low to moderate-risk zones and the rest of all beaches of the Kanthi coast is considered as highly vulnerable zones, based on their geomorphic features (Table 8).

8. Runnel

Runnel is an important feature in restructuring a beach slope by the transportation of fine sand from upward to seaward. Thus, the beach slope is decreased by the work of the runnel. Besides, the beach sedimentary structure is changed which directly influences to wave height and wave energy precipitation or impaction positively. The type of runnel also controls the range of response which is also classified by the risk rating.

Table 9. Runnel Type at the Beaches of Kanthi Coast

Coast	Type of Runnel	Average Rating	Remark (Vulnerability)
Junput	No	0	Very Low
Shoula	No	0	Very Low
Mandarbani	DR, SBR	1.5	High
Tajpur	No	0	Very Low
Shankarpur	DR	2	Very High
Digha	BR, DR, SBR	2	Very High
Talsari	BR, SBR	2	Very High

Source: Field Survey and Observation (2016-19)

Note: SBR = Swash Bar Runnel, DR = Depression Runnel, BR = Bottom –Up Runnel
Rating: SBR = 1, DR = 2, BR = 3.

From the research work, it has been observed that Mandarbani, Shankarpur, Digha, and Talsari are experienced as very high-risk zones due to the presence of a various type of runnel at their beach platform (Table 9).

9. Sand Dune

The sand dune is the natural barrier of the coast. The type of dune is a good indicator to measure the beach condition whether it is faced with erosional or depositional work. Usually, it has been observed that embryo dune and foredune indicate to depositional work means to low-risk zone. Backshore cliffing dunes report to erosional work means high-risk zone. Other dunes are developed due to the modification work of natural agents that indicate to instable conditions or moderate risk zones.

Table 10. Sand Dune Distribution at the Beaches of Kanthi Coast

Coast	Sand Dune	Average Rating	Remark (Vulnerability)
Junput	ED, FD, TD(P), PD	1.50	Very Low
Shoula	ED, FD, TD(P)	1.33	Very Low
Mandarbani	FD, BCD, TD(P)	2.00	Moderate
Tajpur	ED, FD, BCD, PD	1.75	Low
Shankarpur	BCD, TD(P)	2.50	Very High
Digha	TD(P), PD	2.00	Moderate
Talsari	FD, BCD, TD(P), PD	2.00	Moderate

Source: Field Survey and Observation (2016-19)

Note: ED = Embryo Dune (L), FD = Foredune (L), BCD = Backshore Cliffing Dune (H), TD(P) = Parallel or Transverse Dune (M), PD = Parabolic Dune (M), TD = Transgressive Dune (M).
Rating: Low (L) – 1, Medium (M) – 2, High (H) – 3.

From the above computation, it has been measured that Shankarpur is considered as a very high-risk zone (Table 10).

10. Tsunami Run-up

A tsunami occurs due to an earthquake. These wave parameters depend on earthquake source parameters, bathymetry, beach profile, coastal land topography, and the presence of coastal structures (Kumar et al. 2010). According to Smart et al. (2015), 'tsunami risk reduction activities rely on a sound knowledge of the hazard characteristics'. These surges cause flooding of seawater into the land as much as 1 km or even more, resulting in loss of human life and property damage (Kumar et al. 2015). The Kanthi coast is located at the Indo-Burma-Sumatra earthquake zone. The calculation of tsunami runs up estimated by the following equation, according to G. M. Smart et al. (2015).

$$\text{Tsunami Run-up Estimation } (R) = L\, S_0$$

Where,
L = Wavelength
S_0= Uniform Beach Slope

Table 11. Tsunami Run-up of Kanthi Coast

Coast	Wavelength in meter	Beach Slope (in Degree)	Tsunami Arrival Height (m)	Remark (Vulnerability)
Junput	16.58	$0^{o}48'07.43''$	13.298	Very Low
Shoula	6.94	$1^{o}03'0.55''$	7.288	Very Low
Mandarbani	14.48	$1^{o}12'44.99''$	17.557	Low
Tajpur	15.88	$2^{o}01'46.76''$	32.231	Moderate
Shankarpur	17.12	$2^{o}51'29.72''$	48.933	Very High
Digha	20.60	$1^{o}05'18.45''$	22.42	Low
Talsari	7.65	$1^{o}11'36.47''$	9.130	Very Low

Source: Field Survey and Observation (2016-19)

From the above computation, it has been revealed that Shankarpur of Kanthi coast is measured as a highly vulnerable zone, based on tsunami run-up (Table 11).

11. Sediment Grain Diameter of Beach (onshore)

Sediment grain size is directly pronounced to erosion, transportation, and deposition. Fine grains are eroded or transported and coarse grains are deposited by the coastal wave energy. Consequently, sediment grain size is an important measurement to compute vulnerability.

Table 12. Sediment Grain Diameter of Kanthi Coast

Coast	Mean Grain Size (mm)	Remark (Vulnerability)
Junput	0.117	Very High
Shoula	0.120	Very High
Mandarbani	0.160	Very Low
Tajpur	0.164	Very Low
Shankarpur	0.161	Very Low
Digha	0.123	Very High
Talsari	0.148	Low

Source: Field Survey and Observation (2016-19)

Mandarbani (0.160 mm), Tajpur (0.164), and Shankarpur (0.161) are considered as a very low-risk zone in comparison to other beaches of the Kanthi coast (Table 12).

12. Sorting of Beach Sediment (onshore)

Sorting is the standard deviation of sediment. The poorly sorted beach is characterized by the maximum porous section that consumes the water and decreases the wave energy dissipation to the beach.

Table 13. Sorting of Beach Sediment of Kanthi Coast

Coast	Sorting (ϕ)	Remark (Vulnerability)
Junput	0.471	Very High
Shoula	0.501	Very High
Mandarbani	0.565	High
Tajpur	0.805	Very Low
Shankarpur	0.559	High
Digha	0.563	High
Talsari	0.512	Very High

Source: Field Survey and Observation (2016-19)

Tajpur (0.805 SD) beach is considered as a very low-risk zone due to the construction of the poorly sorted sedimentary platform in comparison to other beaches on the Kanthi coast (Table 13).

13. CRZ (in % of Violation)

Geological, biological, and ecological influences are the most dynamic domains which affect the environment of the coastal zone. Kanthi cost comes under the coastal regulation zone III (under category I or II) by the letter of S K Mathur, Deputy Secretary to Government of India, Ministry of Environment & Forests to The Chief Secretary, Govt. Of West Bengal on dated 27th September 1996 (Letter Memo No. J-17011/24/92-IA-II). According to rules and regulations, from the high tidal line to 200 meters, towards land are not permitted to any construction or mutation of land. Through the research work, % of CRZ Violation against the total beach length is measured.

Table 14. CRZ Violation (%) at the Beaches of Kanthi Coast

Coast	Beach Length (m)	CRZ Violation Length (m)	% of CRZ Violation	Remark (Vulnerability)
Junput	19904	0.00	0.000	Null
Shoula	1331	0.00	0.000	Null
Mandarbani	14820	6410.07	43.253	Very High
Tajpur	3257	732.86	22.501	Very Low
Shankarpur	6597	2550.23	38.657	High
Digha	6891	1747.01	25.352	Very Low
Talsari	12399	0.00	0.000	Null

Source: Field Survey and Observation (2016-19)

From the above computation, it has been revealed that the Mandarbani (43.25%) coast is experienced maximum coastal regulation violations compared to other beaches of the Kanthi coast (Table 14). Most of these changes are caused by degradation in these ecosystem functions, such as mangrove forest transformation into aquaculture (Handiani et al., 2018; Kepel et al., 2019).

14. Crab Habitat Density (Small and Red)

The burrowing activity by the Crab influences beach sediment structure, soil permeability, and sediment attraction. Above those parameters have been quantified statistically to assess whether it will degradational or depositional coastal beach. During field surveys and laboratory work, it has been observed that crab burrowing on coastal beaches positively pronounces to coastal beach health. High Crab habitat density indicates to stable beach conditions because it makes the beach sedimentary platform as poorly sorted land.

Table 15. Crab Habitat Density at the Beaches of Kanthi Coast

Coast	Small Crab Density (in No. of Habitat/m^2)	Remark (Vulnerability)	Red Crab Density (in No. of Habitat/m^2)	Remark (Vulnerability)
Junput	15	Low	9	Very Low
Shoula	17	Very Low	5	Moderate
Mandarbani	9	Moderate	0	Very High
Tajpur	13	Moderate	3	High
Shankarpur	7	High	1	Very High
Digha	6	High	0	Very High
Talsari	11	Moderate	3	High

Source: Field Survey and Observation (2016-19)

From the research work, it has been observed traced that Mandarbani to Talsari Beach is considered as high to very high-risk zone according to the habitat density of small and red crab at the beach platform (Table 15).

15. Inlet Migration

Tidal inlets of the Kanthi coast is migrated laterally. Estuary and mangroves are natural ecosystems that have been used intensively and have been changing dramatically (Handiani *et al.*, 2022), in the Kanthi coast. By the influence of longshore sediment transport, the majority of tidal inlets are migrated with its direction. Thus, lateral tidal inlet migration is convinced of the beach length and width positively.

Table 16. Inlet Migration Rate at the Beaches of Kanthi Coast

Coast	Inlet Migration Rate (m/y)	Remark (Vulnerability)
Junput	+6.88	Low
Shoula	+3.89	Low
Mandarbani	-3.00	High
Tajpur	+2.61	Low
Shankarpur	+12.90	Very Low
Digha	-16.63	Very High
Talsari	-4.83	High

Source: Field Survey and Observation (2016-19)

Against the base year 1973, it has been measured that the Mandarbani (-3.00 m/y), Digha (-16.63 m/y), and Talsari (-4.83 m/y) coasts are facing highly vulnerable conditions due to negative lateral inlet migration (Table 16). The rest of the beaches of Kanthi Coast report positive inlet migration for longshore drifting.

Table 17. Risk Rating of Kanthi Coastal Beach

No.		Variable	Risk Rating				
			Very Low (1)	Low (2)	Medium (3)	High (4)	Very High (5)
1	Shoreline Change Rate (m/y)	End Point Rate (EPR) in m/y	> 2.0	0.5 – 2.0	-0.5 - 0.5	-2.0 – -0.5	< -2.0
		Net Shoreline Movement (NSM) in m	156.16 - 312.37	10 – 156.19	-10 - 10	-123.74 - -10	-247.48 – -123.74
		Shoreline Change Envelope (SCE) in m	0.0 - 10	10 – 207.37	207.37 – 404.37	404.37 – 601.37	> 601.37
3	Coastal Slope (degree)		$2^o26'49.27''$ - $2^o51'29.73''$	$2^o02'08.81''$ - $2^o26'49.27''$	$1^o37'28.35''$ - $2^o02'08.81''$	$1^o12'47.89''$ - $1^o37'28.35''$	$0^o48'07.43'$ - $1^o12'47.89''$
4	Wave height (m)		0.105 – 0.235	0.235 – 0.365	0.365 – 0.495	0.495 – 0.625	0.625 – 0.755
6	Regional Elevation (m)		8.614 – 9.510	7.718 – 8.614	6.822 – 7.718	5.926 – 6.822	5.03 – 5.926
8	Runnel		0.0 – 0.4	0.4 – 0.8	0.8 – 1.2	1.2 – 1.6	1.6 – 2.0
9	Sand Dune		1.33 – 1.564	1.564 – 1.798	1.798 – 2.032	2.032 – 2.266	2.266 – 2.5
8	Tsunami Run up (m)		7.288 – 15.617	15.617 – 23.946	23.946 – 32.275	32.275 – 40.604	40.604 -48.933
10	Mean Grain Size (mm)		0.155 – 0.164	0.145 – 0.155	0.136 -0.145	0.126 – 0.136	0.117 – 0.126
12	Sorting		0.738 – 0.805	0.671 – 0.738	0.605 – 0.671	0.538 – 0.605	0.471 – 0.538
13	CRZ Violation (%)		< 26.65	26.65 – 30.80	30.80 – 34.95	34.95 – 39.10	>39.10
14	Crab Habitat Density (in m^2)	Small Crab	0 – 4	4 – 8	8 – 12	12 – 16	16 – 20
		Red Crab	0 – 2	2 – 4	4 – 6	6 – 8	8 – 10
15	Inlet Migration (m/y)		>10	1 – 10	-1 – 1	-1 - -10	<-10

Source: Researcher's Computation

Vulnerability Assessment

The vulnerability in the coastal zone is being accessed by system susceptibility, resilience, and resistance, allowing adaptive management plans to be developed in perspective with the latest Intergovernmental Panel on Climate Change (IPCC) report (Masson-Delmotte et al., 2022). Coastal vulnerability assessments are improving, with more regular evaluation of the impact of various vulnerabilities and platforms that facilitate the visualization of coastal vulnerability, but there are still substantial problems in producing and enhancing coastal vulnerability assessments. Identifying the factors to include in the collection of data, even including socioeconomic vulnerabilities, are all challenges (Schmitt et al., 2017; Ehsan et al., 2022).

The CVI model proposed by Gornitz (1990) can assess the coastal vulnerability to SLR, particularly due to erosion and/or inundation (Lu et al., 2022). Coastal vulnerability is also a popular assessment of the coastal environment prone to significant hazards, such as coastal storms, erosion, and inundation (Contestabile and Vicinanza, 2020). The quantification of the coastal vulnerability index (CVI) has been extensively studied and well-developed in the past several years (Lu et al., 2022). The CVI is determined by combining the relative risk variables to create a single indicator (Kumar et al. 2010). If each variables of the coastline are in a risk situation, then CVI is calculated as the square root of the product of the ranked variables which is divided by the total number of variables. The risk parameters have been rated on their percentile value and the beaches have been classified into five classes viz. Very low (<20th percentile), low (20th – 40th percentile), Moderate (40th – 60th percentile), and high (60th – 80th percentile), very high (>80th percentile) vulnerable zone. Five coastal vulnerability assessments used a scaling or weight factor for each variable (Nidhinarangkoon & Ritphring, 2019). All the fifteen variables of the beaches of Kanthi coast are classed according to the above-mentioned percentile value and also follow the risk rating classification by Kumar et al. (2010) (Table 17).

Table 18. Vulnerability Assessment of Kanthi Coastal Beach

No	Variable \ Beach		Junput	Shoula	Mandarbani	Tajpur	Shankarpur	Digha	Talsari
1	Shoreline Change rate (m/y)	End Point Rate (EPR) in m/y	1	1	4	5	5	5	5
		Net Shoreline Movement (NSM) in m	1	3	2	4	4	5	5
		Shoreline Change Envelope (SCE) in m	2	1	3	4	4	5	5
2	Sea-level Change rate (mm/y)		3	3	3	3	3	3	3
3	Coastal Slope (degree)		5	5	5	3	1	5	5
4	Wave height (m)		1	1	1	3	1	5	2
5	Tidal Range (m)		3	3	3	3	3	3	3
6	Regional Elevation		3	5	5	3	3	1	4
7	Geomorphic features		3	1	5	5	5	5	2
8	Runnel Distribution		1	1	4	1	5	5	5
9	Sand Dune Distribution		1	1	3	2	5	3	3
10	Tsunami Run up (m)		1	1	2	3	5	2	1
11	Mean grain Size (mm)		5	5	1	1	1	5	2
12	Sorting		5	5	4	1	4	4	5
13	CRZ Violation (%)		0	0	5	1	4	1	0
14	Crab Habitat Density (No./m^2)	Small Crab	2	1	3	3	4	4	3
		Red Crab	1	3	5	4	5	5	4
15	Inlet Migration (m/y)		2	2	4	2	1	5	4
Total			40	42	62	51	63	71	61
CV Rating			1.633	1.673	2.033	1.844	2.049	2.176	2.017

Source: Researcher's Computation

The coastal vulnerability of Kanthi coastal beach is assessed based on above mentioned fifteen variables (Table 18). The score ranges and ranking are summarized in Table 18 (Koroglu et al., 2019; Wang et al., 2021).

Table 19. Coastal Vulnerable Zone of Kanthi Coastal Beach

CV Rating	Vulnerability	Beach of Kanthi Coast
Below 1.7	Low	Junput, Shoula
1.700 – 1.881	Moderate	Tajpur
1.881 – 2.062	High	Mandarbani, Shankarpur, Talsari
Above 2.062	Very High	Digha

Source: Researcher's Computation

The coastal stretches of the Kanthi coast are classed into four vulnerable zones, *viz.*, low, moderate, high, and very high to the fifteen relative risk variables. The resultant CVI is calculated and the vulnerability zones along the coastal shoreline are delineated on the map (Figure 8) (Kumar et al., 2010). From the above computation and observation, it has been revealed that Junput and Shoula come under the low vulnerable zone, Tajpur is reported as a moderately vulnerable zone, Mandarbani, Shankarpur, and Talsari are accompanied as high vulnerable zone and Digha is considered as the very high vulnerable zone of Kanthi coast (Table 19).

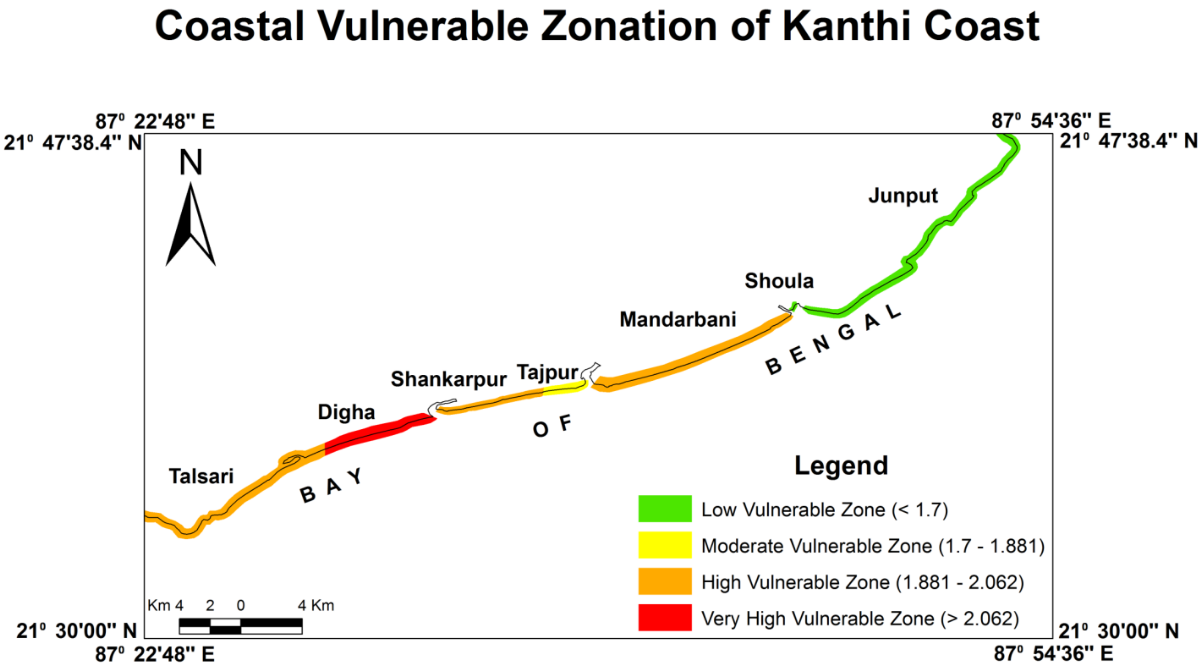

Figure 7. Coastal Vulnerable Zonation of Kanthi Coast

Problems

Coastal regions are one of the essential spots on the earth as they are hosts to various important ecosystems, natural resources, and the increasing population (Oloyede et al., 2022). The problem of the coast is synonymous with the development. In recent years, due to their special locations and unique natural resources, the artificial landscape areas in the coastal regions have been expanding, and consequently, their landscape patterns have been remarkably changed (Zhu et al., 2018; Lu et al., 2022). Other than the land-based sources, the marine construction boom driven by the expansions of coastal cities, increasing population, and economic development including the constructions built in the marine environment with a wide range of purposes (ports and dams of aquaculture) also contributes to the changes in coastline and hydrodynamics, and causes natural disasters (SLR, storm surge and typhoons) (Arkema et al., 2013; Jiang et al., 2021; Huang et al., 2022). Our general methodology for development is directly linked with concretization. During the said development, we ignore and interrupt the nature that occurs in the various types of problems in different intensities. These hazards pose threats to the coastal physical, economic, and social systems (Handiani et al., 2022). There is an equilibrium that exists between all living organisms and nature. This balance is maintained by some natural mechanisms. Nature continuously is trying to keep balance through different calamities that are named as the problem. Problems at the Kanthi coast are

1. Seawater Intrusion

The Digha, Shankarpur, Tajpur, and Mandarbani coasts are developed as important tourist spots. Consequently, huge numbers of hotels, motels, lodges, etc are constructed along the beach in an unplanned way. Groundwater is the only water source there. Due to over pulling of ground, water seawater infiltrates into groundwater to keep the water level.

2. Over Trapping

All the beaches of Kanthi coast are associated with low beach slope that introduces to high wave heights during the storm. Thus, over a trapping problem is occurs near the Talsari to Mandarbani beach.

3. Concrete Embankment (Chocked the percolation)

The regency experiences erosion along their coast and it is causing loss of coastal land and infrastructure and geomatics, natural hazards, and a risk of 1179 building damages (Handiani et al., 2018). The concrete embankment is a hard technology for protection against beach erosion. At Digha (Fully), Talsari (eastern part), Shankarpur (middle part), and Mandarbani (middle part) concrete and boulder embankments are constructed. The consecrated embankment reduces the water percolation rate. Thus, maximum wave energy dissipates on the beach platform which influences to beach erosion. Besides, it has been observed that bottom-up runnel is found at the bottom of the embankment which also helps to erosion the fine sediment and after several years the embankments are disrupted and uprooted.

4. Beach Carrying Capacity

It is not possible to define the beach carrying capacity by any specific definition. According to WTO, it is clear that the beach is an area that is dedicated to tourists for their enjoyment. This is the maximum number that the area is able to support (Kurhade, 2013). It has been researched that tourist inflow overflows on the beach carrying capacity during season time. Due to human activity, the coastal system becomes more vulnerable with every natural disaster (Noor et al., 2022).

5. Crab Habitat

Crab burrows are essential for beach sustainability. However, at the Kanthi coast, especially at the Talsari to Mandarbani beach crab natural habitat is directly interrupted for tourism (Small crab) and the construction of concrete embankment (Red crab).

6. CRZ Violation

The country is facing many environmental problems including in its coastal zones, due to numerous pressures caused by rapid and unplanned or poorly planned industrial and economic development (Yoo et al., 2014; Rudiarto et al., 2018; Glaeser, 2019). The rapidly increasing urbanization, severe pollution, industrial development, tourism, and over-exploitation of coastal resources are the main causes of coastal zone depletion. These are responsible for most of the hazards which are very common phenomena in these regions. Through research work, it has been traced that coastal regulation zone (CRZ) violation is an important issue, especially is in Mandarbani Beach.

7. Joy Rides

Digha and Mandarbani is an important tourist destinations and joy rides are an important part of their beach tourism. Now oil spilling is a serious issue that derives from it.

8. Coastal Erosion

Coastal vulnerability is a spatial concept that identifies people and places that are susceptible to disturbances resulting from coastal hazards (Bevacqua et al., 2018). From the geomorphological point of view, beach erosion is not a problem but also it is a part of coastal dynamism. Presently, coastal erosion is a serious threat to the beach-associated villages of the Kanthi coast.

9. Unplanned Social Forestry (Jhaw)

Unplanned social forestry of Jhaw is also a prominent cause of coastal erosion. At the coast, two natural agents are pronounced, viz. Coastal wave and wind. Natural vegetation controls the depositional work along the shoreline. The dune is the resultant landform of wind and natural vegetation mainly Keya plant plays an important role in the formation. Usually, wind affects from the ground to 1.5m up. Thus, the Keya plant is more suitable for wind-driven sediment attraction than the Jhaw.

10. Others

a. Natural Ecosystem Disruption
b. Pollution (for tourism)
c. Saltation of the agricultural land
d. Occupational problem
e. Flooding

CONCLUSION

In the present situation, the global climate is polluted by unscientific human interruptions and their modern industrialized civilization. As a result, the climate totally changed. Therefore, it is necessary to know the continuance of human civilization with the help of coastal vulnerability zone assessment. In this paper, some common parameters such as Rate of shoreline change, sea level change rate, beach slope, wave height, tidal range, regional elevation, geomorphic features, coastal sediment properties, and violation ratio are taken for measurement. The main objective is to identify the causes behind this type of coastal erosion which are quite common in many parts of the coastal areas. It is known that many coastal areas face vulnerable geomorphic situations and some solutions are needed to mitigate this hazardous situation.

From this research work, it has been examined that the western segment of the Kanthi coast (Digha, Shankarpur, and Mandarbani from west to east) are experiencing more erosional work. Due to the extreme pressure of tourists pronouncing the beach erosion. This research paper presents some possible measures to mitigate this problem and also contribute to protecting human civilization from terrible outbreaks of global climate change. It is a critical issue to allocate coastal land and proper management of the coastal resources. The coastal zone of Kanthi coast and the adjacent area is under alarming circumstances for increasing pressure of population, rapid urbanization, pollution, unplanned tourism development, aquaculture and habitat alterations or land use and land cover alterations. All the issues should be tackled and partially solved by short-term and long-term measures. For management of the coastal belt, assessment is needed to identify the capacity of the alluvium coast to adjust with the morph dynamics under a high-energy environment.

Short Term Measures: (1) Keya or natural vegetation should be planted along the shoreline; (2) Grow up social awareness against pollution and beach protection; (3) Rain Water harvesting; (4) Stop the CRZ violation strictly; (5) Educate the tourist about the coastal environment sensitivity and Control the tourist flow according to the carrying capacity.

Long Term Measures: (1) To stop the coastal erosion at the beaches of Kanthi coast should construct the breakwater bar with the angel of longshore drift at Talsari to Tajpur coast towards the sea; (2) Consecrate embankment and boulder dam should be decommissioned; (3) Coast associated urban and semi-urban town should be grown according to the proper scientific planning with the maintaining the CRZ rules and regulation of Govt. of India; (4) Crab habitat should be rehabilitated by the Government and NGO initiative. Coarse Sediment should be employed artificially to make a poorly sorted beach platform that reduces the wave energy impaction. However, it is too much price consuming.

REFERENCES

Anfuso, G., & Del Pozo, J. Á. M. (2009). Assessment of coastal vulnerability through the use of GIS tools in South Sicily (Italy). *Environmental Management*, 43(3), 533-545.

Arkema, K. K., Guannel, G., Verutes, G., Wood, S. A., and Silver, J. M. (2013). Coastal habitats shield people and property from sea-level rise and storms. Nat. Climate Change, 3, 913–918.

Athanasiou, P.; van Dongeren, A.; Giardino, A.; Vousdoukas, M.; Gaytan-Aguilar, S.; Ranasinghe, R. (2019). Global distribution of nearshore slopes with implications for coastal retreat. *Earth Syst. Sci. Data*, 11, 1515–1529

Barman, N. K., Chatterjee, S., & Paul, A. K. (2016). Estimate the coastal vulnerability in the Balasore Coast of India: A statistical approach. *Modeling Earth Systems and Environment*, 2(1), 20.

Bevacqua A, Yu D, Zhang Y. (2018). Coastal vulnerability: evolving concepts in understanding vulnerable people and places. *Environ Sci Policy*, 82, 19–29.

Boateng, I. (2012). GIS assessment of coastal vulnerability to climate change and coastal adaption planning in Vietnam. *Journal of Coastal Conservation*, 16(1), 25-36.

Contestabile P, Vicinanza D. (2020). Coastal vulnerability and mitigation strategies: from monitoring to applied research. *Water*, 12(9), 2594.

Demirkesen, A. C., & Evrendilek, F. (2017). Compositing climate change vulnerability of a Mediterranean region using spatiotemporally dynamic proxies for ecological and socioeconomic impacts and stabilities. *Environmental monitoring and assessment*, 189(1), 1-15.

Dian N. Handiani, Aida Heriati & Wina A. Gunawan (2022). Comparison of coastal vulnerability assessment for Subang Regency in North Coast West Java-Indonesia. *Geomatics, Natural Hazards and Risk*, 13(1), 1178-1206.

Dulal HB. (2019). Cities in Asia: how are they adapting to climate change? *J Environ Stud Sci*., 9(1),13–24.

Ehsan, S.; Begum, R.A.; Maulud, K.N.A. (2022). Household external vulnerability due to climate change in Selangor coast of Malaysia. *Clim. Risk Manag*., 35, 100408.

Elkhateeb, W.A.; Zaghlol, G.M.; El-Garawani, I.M.; Ahmed, E.F.; Rateb, M.E.; Abdel Moneim, A.E. (2018). Ganoderma applanatum secondary metabolites induced apoptosis through different pathways: In vivo and in vitro anticancer studies. *Biomed. Pharmacother*., 101, 264–277.

Felsenstein, D., & Lichter, M. (2014). Social and economic vulnerability of coastal communities to sea-level rise and extreme flooding. *Natural hazards*, 71(1), 463-491.

Glaeser B. (2019). Sustainable coastal management for social-ecological systems—A typology approach in Indonesia. *Coast. Manag*. 61–77.

Gornitz, V. (1990). Vulnerability of the East Coast, U.S.A. to Future Sea Level Rise. *Journal of Coastal Research*, (9), 201–237.

Guillard-Gonçalves, C.; Zêzere, J.L. (2018). Combining Social Vulnerability and Physical Vulnerability to Analyse Landslide Risk at the Municipal Scale. *Geosciences*, 8, 294.

Handiani DN, Darmawan S, Hernawati R, Suryahadi MF, Aditya YD. (2018). Coastline change and coastal ecosystem identification in Subang Regency [Identifikasi Perubahan Garis Pantai dan Ekosistem Pesisir di Kabupaten Subang]. *JRG*. 2017(2):61–71.

Hegde, A. V. & Reju, V. R. (2007). Development of Coastal Vulnerability Index for Mangalore Coast, India, *Journal of Coastal Research*, (23), 1106–1111.

Hossain, Sk A. et al. (2022). Coastal vulnerability assessment of India's Purba Medinipur-Balasore coastal stretch: A comparative study using empirical models, *International Journal of Disaster Risk Reduction*, 77.

Huang, M., Xia, C., Li, Y., Zeng, C., and Zhang, B. (2022). Coupling responses of landscape pattern to human activity and their drivers in the hinterland of three gorges reservoir area. *Global Ecol. Conserv*., 33, e01992.

Jiang, S., Xu, N., Li, Z., and Huang, C. (2021). Satellite derived coastal reclamation expansion in China since the 21st century. *Global Ecol. Conserv*., 30, e01797.

Kar, S. (2018). The Study of The Vulnerability of The East Coast India. *International Journal of Engineering Science Invention (IJESI)*, 07(07), 01-08.

Kepel TL, Heriati A, Mbay L, Ati R, Jayawiguna MH, Abida RF. 2019. Mangrove rehabilitation as coastal abrasion defenses in North Coast Java. [Rehabilitasi Mangrove sebagai Pelindung Abrasi Pantai di Pesisir Pantura Jawa]. In: Solihuddin, T., Jayawiguna, M. H., Triyono, editors. North Coast Java strategies based on coastal zone dynamic [Strategi Rehabilitasi Pantura Jawa Berdasarkan Dinamika Wilayah Pesisir]. Jakarta: AMAFRAD Press, Marine Research Center, Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF), Indonesian. p. 53–75.

Koroglu, A., Ranasinghe, R., Jiménez, J., and Ali, D. (2019). Comparison of coastal vulnerability index applications for Barcelona province. *Ocean Coast. Manag*. 178, 104799.

Krampe F, Mobjork M. 2018. Responding to climate-related security risks: reviewing regional organizations in Asia and Africa. *Curr Clim Change Rep*. 4(4), 330–337.

Kumar, T. S., Mahendra, R. S., Nayak, S., Radhakrishnan, K., & Sahu, K. C. (May 2010). Coastal Vulnerability Assessment for Orissa State, East Coast of India, *Journal of Coastal Research*, 26(3), 523-534.

Kurhade, S. Y. (2013). Methodological Framework for Evaluation of Tourism Carrying Capacity of Eco Sensitive Region. *International Journal of Innovative Research in Science*, Engineering and Technology, 2, (3), 781-786.

Lu J, Zhang Y, Shi H and Lv X (2022). Coastal vulnerability modelling and social vulnerability assessment under anthropogenic impacts. *Front. Mar. Sci*., 9, 1015781.

Lu, X. Q., and Zhang, J. C. (2006). Numerical study on spatially varying bottom friction coefficient of a 2D tidal model with adjoint method. *Cont. Shelf Res*. 26, 1905–1923.

Mahapatra, M., Ramakrishnan, R., & Rajawat, A. S. (2015). Coastal vulnerability assessment using analytical hierarchical process for South Gujarat coast, India. *Natural Hazards*, 76(1), 139- 159.

Mahapatra, M., Ramakrishnan, R., & Rajawat, A. S. (2015). Coastal vulnerability assessment of Gujarat coast to sea level rise using GIS techniques: a preliminary study. *Journal of Coastal Conservation*, 19(2), 241-256.

Mahapatra, M.; Ratheesh, R.; Rajawat, A.S. Sea level rise and coastal vulnerability assessment: A review. *Int. J. Geol. Earth Environ. Sci.*, 3, 67–80.

Masson-Delmotte, V.; Zhai, A.; Pirani, S.L.; Connors, C.; Péan, S.; Berger, N.; Caud, Y.; Chen, L.; Goldfarb, M.I.; Gomis, M.; et al. (2022). Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In Climate Change 2022: Impacts, Adaptation, and Vulnerability; Cambridge University Press: Cambridge, UK.

Mujabar, P. S., & Chandrasekar, N. (2013). Coastal erosion hazard and vulnerability assessment for southern coastal Tamil Nadu of India by using remote sensing and GIS. *Natural Hazards*, 69(3), 1295-1314.

Nicholls RJ, Wong PP, Burkett VR, Codignotto JO, Hay JE, McLean RF, Ragoonaden S, Woodroffe CD, Parry ML, Canziani OF, et al. (2018). Coastal systems and low-lying areas. In Climate change 2007: impacts, adaptation and vulnerability. Contribution of WorkingGroup II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK: Cambridge University Press.

Nicholls, R. J., Wong, P. P., Burkett, V., Codignotto, J., Hay, J., McLean, R., ... & Saito, Y. (2007). Coastal systems and lowlying areas.

Nicholls, R. J., Wong, P. P., Burkett, V., Woodroffe, C. D., & Hay, J. (2008). Climate change and coastal vulnerability assessment: scenarios for integrated assessment. *Sustainability Science*, 3, 89–102.

Nidhinarangkoon, P.; Ritphring, S. Assessment of coastal vulnerability to sea level rise: A case study of Prachuap Khiri Khan, Thailand. *IOP Conf. Ser. Earth Environ. Sci*. 2019, 326, 012005.

Ningsih NS, Hanifah F, Tanjung TS, Yani LF, Azhar MA. (2020). The effect of tropical cyclone Nicholas (11–20 February 2008) on sea level anomalies in Indonesian Waters. *JMSE*. 8(11): 948.

Noor, N.M.; Abdul Maulud, K.N. (2022). Coastal Vulnerability: A Brief Review on Integrated Assessment in Southeast Asia. *J. Mar. Sci. Eng.*, 10, 595.

Oloyede, M.O.; Williams, A.B.; Ode, G.O.; Benson, N.U. (2022). Coastal Vulnerability Assessment: A Case Study of the Nigerian Coastline. *Sustainability*, 14, 2097.

Pandey, R., Shukla, Dr.R.K. (April 2018). Extraction of Digital Elevation Model (DEM) of Uttarkashi District (Uttrakhand, India) Using SRTM Data in Open Source QGIS, *International Journal of Creative Research Thought* (IJCRT), 6(2), 143-151.

Parthasarathy, K. S. S. *et al.* (2018). Shoreline Change Detection Using Geo-Spatial Techniques- A case Study for Cuddalore Coast", *6th International Symposium on Advances in Civil and Environmental Engineering Practices for Sustainable Development (ACEPS)*, 33-39.

Paul, A. et al. (2020). Multicriteria Assessment of Coastal Vulnerability Index with the help of

GIS Techniques: A Study in Digha, Shankarpur, Mandarmani and Junput Coast, India. *Journal of Coastal Science*, 7(2), 1-13.

Purbani D, Salim HL, Marzuki MI, Abida RF, Tussadiah, A, Triyono. (2019). Abrasion and accretion in the last decades case study: Serang, Indramayu, Brebes, Demak, and Gresik Districts [Laju Abrasi dan Akresi Pantura Jawa dalam Satu Dekade Terakhir Studi Kasus: Kabupaten Serang, Indramayu, Brebes, Demak, dan Gresik]. In: Solihuddin, T., Jayawiguna, M. H., Triyono, editors. North Coast Java strategies based on coastal zone dynamic [Strategi Rehabilitasi Pantura Jawa Berdasarkan Dinamika Wilayah Pesisir]. Jakarta: AMAFRAD Press, Marine Research Center, Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF), Indonesian. p. 37–51.

Rudiarto I, Handayani W, Sih Setyono J, Jawoto Sih Setyono (2018). A regional perspective on urbanization and climate-related disasters in the Northern Coastal Region of Central Java, Indonesia. *Land*. 7(1), 34.

Schmitt, R.; Rubin, Z.; (Kondolf, G. 2017). Losing ground—scenarios of land loss as consequence of shifting sediment budgets in the Mekong Delta. *Geomorphology*, 294, 58–69.

Solihuddin T, Dhiadudin R, Mustikasari E, Rahayu YP, Husrin S. (2019). North Coast Java rehabilitation: issues, analysis, and challenges [Rehabilitasi Pantura Jawa: Isu, Analisis dan Tantangan]. In: Solihuddin, T., Jayawiguna, M. H., Triyono, editors. North Coast Java strategies based on coastal zone dynamic [Strategi Rehabilitasi Pantura Jawa Berdasarkan Dinamika Wilayah Pesisir]. Jakarta: AMAFRAD Press, Marine Research Center, Ministry of Fisheries and Marine Affairs Republic of Indonesia (MoMAF). 9–35.

Thomas V, Lopez R. (2015). Global Increase in Climate-Related Disasters. No. 466. ADB economics working paper series. Manila, Philippine: *Asian Development Bank*. 1–45.

Wang, C., Cai, L., Wu, Y., and Ouyang, Y. (2021). Numerical simulation of the impact of an integrated renovation project on the maowei Sea hydrodynamic environment. *Sci. Rep*. 11, 17059.

Willemsen P, van der Lelij AC, van Wesenbeeck B. (2019). Risk assessment North Coast Java. Deltares, Report Project No. 1220476-002-ZKS-0007. p. 1–25.

Yadav, A. B. et al. (2022). Coastal Vulnerability Assessment: A case study of the Ratnagiri coast, Maharashtra, India; Earth and Environmental Science, *IOP Publishing*, 1-9.

Yoo G, Kim AR, Hadi S. 2014. A methodology to assess environmental vulnerability in a coastal city: application to Jakarta, Indonesia. *Ocean Coast Manage*. 102:169–177.

Zikra M, Suntoyo L. 2015. Climate change impacts on Indonesian coastal areas. *Procedia Earth Planetary Sci*., 14, 57–63.