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Spatial Characteristics Analysis of Coastal Vulnerability in the Balasore Coastal District, Odisha, India

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ABSTRACT

Climate change related enhanced weather related natural hazards, in the form of frequent high intensity tropical cyclones, storm surges, coastal ecological adverse changes and allied hazards have made Balasore district of Odisha an environmentally degraded coastal vulnerable zone.Since it is paramount to safeguard such vulnerable coastal segments both the scientists and administrators have decided to develop needed maps that bring out vulnerability levels of coastal corridor and inland stretches for arresting further degradation through organised disaster management initiatives. As a part of such an initiative, the present study covenant with the coastal vulnerability for this zone has been carried out by calculating the probability of vulnerability and assigning different levels of vulnerability in the form of weighted score of vulnerability at the Gram Panchayat level in respect of four major resources like land, water, house/shelter and transport in accordance with the dimensional impacts of dominated coastal hazards like cyclone, flood, storm surges, beach erosion, wave action and salinity encroachment. The present study has been conducted among five social groups, as respondent, to recognize the change potential (whether it is enhanced or reduced or no change) of concern resource type subsequent to the hazards occurrence. Nature and composition of such changes may vary from place to place and situation to situation. However, principle of binomial test (as applied in sign test) can be used for determining the probability for each of the variables under every resource type.After getting the vulnerability of probability, it has been multiplied with the respective population to calculate the Coastal Vulnerability Score (CVS) of a particular coastal Gram Panchayat (considered spatial scale to study). This is the first such study that has been undertaken for a part of the Balasore coast. The vulnerability map, prepared for the Balasore coastal district under this study can be used at different coastal stretches to prepare the spatial variability of coastal vulnerability and also formulate the executive management plan.

Key words: probability of coastal vulnerability; coastal vulnerability score; recurring storm flood; Coastal areas.

INTRODUCTION

The inference of coastal vulnerability to climate change involves several concepts that must be clearly defined. The concept of vulnerability is defined differently in the various scientific areas in which it is used (Füssel, 2010) and is closely related to other concepts, such as hazard, risk and resilience. Hazards can be of a technological origin or associated with natural extreme events (like storm surges and tsunamis), some of them specifically influenced by climate change and sea level rise, leading to threats and damages to the population, the environment and/or material assets (Schmidt-Thomé and Kallio, 2006). The concept of risk combines the probability of occurrence of an event with the likely impacts or consequences associated with the event (ETC-ACCor ETC/ACC, 2008). Risk therefore is strictly related to the quantitative (whenever possible, for example through the analysis of historical datasets) or qualitative estimation of probability of possible events. Resilience can be described as the amount of disturbance that a system can absorb while still remaining in the same state or maintaining its functions. In other words it is the degree to which a system is capable of reorganisation and renewal or the degree to which a system can build and increase its adaptive capacity (ETC-ACCor ETC/ACC, 2008). Given the close relation between resilience and natural adaptive capacity, some authors use them synonymous (Nicholls et al., 2007).

The glossaries of the IPCC Third and Fourth Assessment Reports define vulnerability to climate change as the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes. According to the IPCC vulnerability is a function of the character, magnitude, and rate of climate change to which a system is exposed, its sensitivity and its adaptive capacity (IPCC, 2001; 2007). This definition implies three important concepts: exposure, sensitivity and adaptive capacity. Exposure defines the nature and amount to which the system is exposed to climate change phenomena, sensitivity reflects the system's potential to be affected (adversely or beneficially) by such changes, while adaptive capacity describes the system's ability to evolve (autonomously or according to planned measures) in such a way as to maintain (totally or at least

Table 1. The following data set for the 87 (including Balasore Municipal area) Gram Panchayats of Balasore district, Odisha, India, under three components of vulnerability.

Components	Indicators	Functional relationship with coastal hazard (s)
Exposure	Coastal and reverine high astronomical flood	Positive (+)
	Strong wind (cyclone)	Positive (+)
	Storm surge	Positive (+)
	Wave intensity	Positive (+)
	Beach breaching	Positive (+)
Sensitivity	Percentage of gross area flooded	Positive (+)
	Flood magnitude i.e. Depth, Duration, Velocity, Landward extension of coastal flood,	Positive (+)
	Velocity of cyclone	Positive (+)
	Height of storm surge	Positive (+)
	Significant wave height	Positive (+)
	Rate of beach erosion	Positive (+)
Adaptive capacity	Regulations	Negative (-)
	Planning	Negative (-)
	Alarming system and its reliability	Negative (-)
	Compensation against losses	Negative (-)
	Awareness	Negative (-)
	Institutional co-operation	Negative (-)
	Health care	Negative (-)

partially) its key functions in the face of external changes. The vulnerability of coastal systems to sea-level rise and to other drivers of change is determined by their sensitivity, exposure and adaptive capacity (Nicholls and Klein, 2005). The relationships between all the above concepts can be integrated in the conceptual framework for climate change impacts, vulnerability, disaster risks and adaptation options shown in Figure 1.

The IPCC definitions of vulnerability to climate change, and its related components (exposure, sensitivity, and adaptive capacity) provide a suitable starting position to explore possibilities for vulnerability assessment. But,they are not operational. Therefore, a vulnerability assessment should start by defining the policy or scientific objective as clearly as possible and to choose the scope and methods accordingly. Key questions in the scoping phase include: What is vulnerable or what specific parts of the system are most vulnerable? Which impacts are relevant? Vulnerable to what climate change effects? What is the timeframe involved in the vulnerability assessment? Indeed the operational definition of the vulnerability concept is related to the specific issue and/or context (e.g. the coastal area) addressed by the analysis, also imply that spatial and temporal variations of vulnerability in general and coastal hazard vulnerability in particular are taken into consideration, as described in the study in Table 1.

A coastal vulnerability index has been developed by Hegde and Reju (2007) for the Mangalore coast by means of some parameters like geomorphology, regional coastal slope, shoreline change rates and population. They also noted that some physical parameters like wave height, tidal range, probability of storm, etc. can enhance the quality of the CVI(Coastal Vulnerability Index). Future sea level rise and associated coastal vulnerability in the coastal stretch of United States was clearly considered by Gornitz (1990). Building vulnerability (BV) in connection with tsunami exposure is also a major part of the coastal vulnerability, which was weighed up by Dominey-Howes and Papathoma (2003) using the worst case of the tsunami scenario of 7 February 1963, for two coastal villages in the Gulf of Corinth, Greece by the help of tsunami vulnerability assessment method. The result showed 46.5%of all buildings are classified as highly vulnerable (BV) and 85% of all businesses and 13.7% of the population are located within buildings have a high BV classification. From the coastal hazard point of view Rajawat et al. (2006) delineated the hazard line along the Indian coast using data on coastline displacement, tide, waves and elevation. In this connection and in respect to the tsunami wave of 26 December 2004 in Indian coast, Pradeep Kumar and Thakur (2007) assessed the role of bathymetry in modifying the propagation of hazardous wave like tsunami and

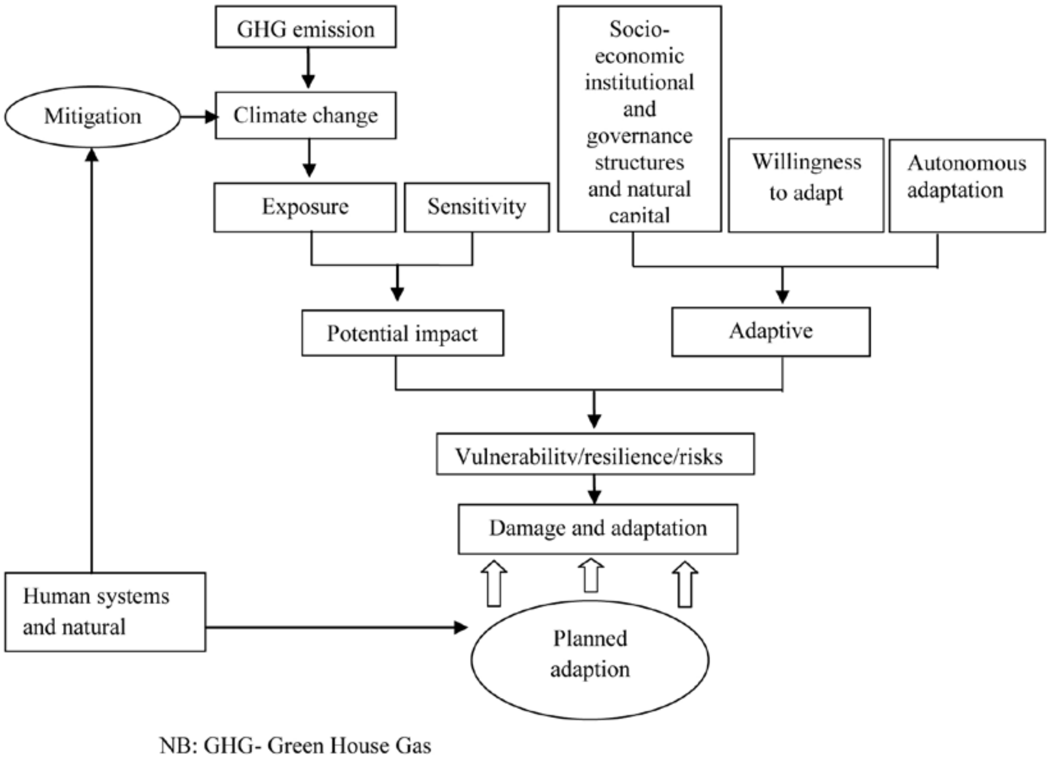

Figure 1. Conceptual framework for climate change impacts, vulnerability, disaster risks and adaptation options (Source: EEA, 2010a, 2010b; ETC-ACC, 2008).

concluded that under sea configuration has an important role in enhancing the wave height because some coastal stations on the eastern margin of India have suffered maximum damage wherein bathymetry has shown an anomalous pattern. Present worst signature of climate induced sea level rise and connected coastal vulnerability will bring profound effects on the low lying coastal zone. This was vividly studied by Dinesh Kumar (2006) with the help of sea level rise data.

In accordance with sea level rise scenario, Belperio et al. (2001) assessed the impact by considering elevation, exposure, aspect and slope of the coastal restraint Belperio et al. (2001)surveillance indicated that the coastal vulnerability is strongly correlated to elevation and exposure, and modelling of coastal processes at regional scale may be suitable as a "first cut" in assessing coastal vulnerability to sea-level rise in tide-dominated, sedimentary coastal regions. A new dimension of assessment of the coastal vulnerability was introduced by Thieler and Hammer-Klose (1999).They assessed the coastal vulnerability of U.S. Atlantic coast by using the physical parameters like coastal slope, geomorphology, shoreline change rate, mean tidal range and mean wave height and also the relative sea-level rise rate.

The result showed that 28% , 24%, 22% and 26% of the U.S. Atlantic coast is of low, moderate high and very high vulnerable categories, respectively. Pendleton, Thieler, and Jeffress (2005) assessed the coastal vulnerability of Golden Gate National Recreation area mainly due to sea level rise by calculating a coastal vulnerability index (CVI) based on both geologic (shoreline-change rate, coastal geomorphology, coastal slope) and physical process variables (sea-level change rate, mean significant wave height, mean tidal range). The CVI allows the six variables to be related in a quantifiable manner that expresses the relative vulnerability of the coast to physical changes due to future sea-level rise.

STUDY AREA

The area under study comes under a part of the alluvial covered coast of the Subarnarekha delta plain. It extends from the mouth of the Subarnarekha River to the Talsari channel along the Bay of Bengal coast of Odisha. The study area lies between 86°52'45"E to 87°31'37"E and 21°20'25"N to 22°07'55"N Figure 2. The area is a coastal alluvial tract with unconsolidated substrates, and this stretch of the coastline is geomorphologically dynamic, rich in habitat diversity and prone to hazards such as tropical cyclone-induced tidal waves, storm surges and consequent coastal flooding.

The land consists of a monotonously flat alluvium surface that lies between 2.5 to 3.5 m above mean sea level (MSL).Geologically, the area is characterized by alluvium

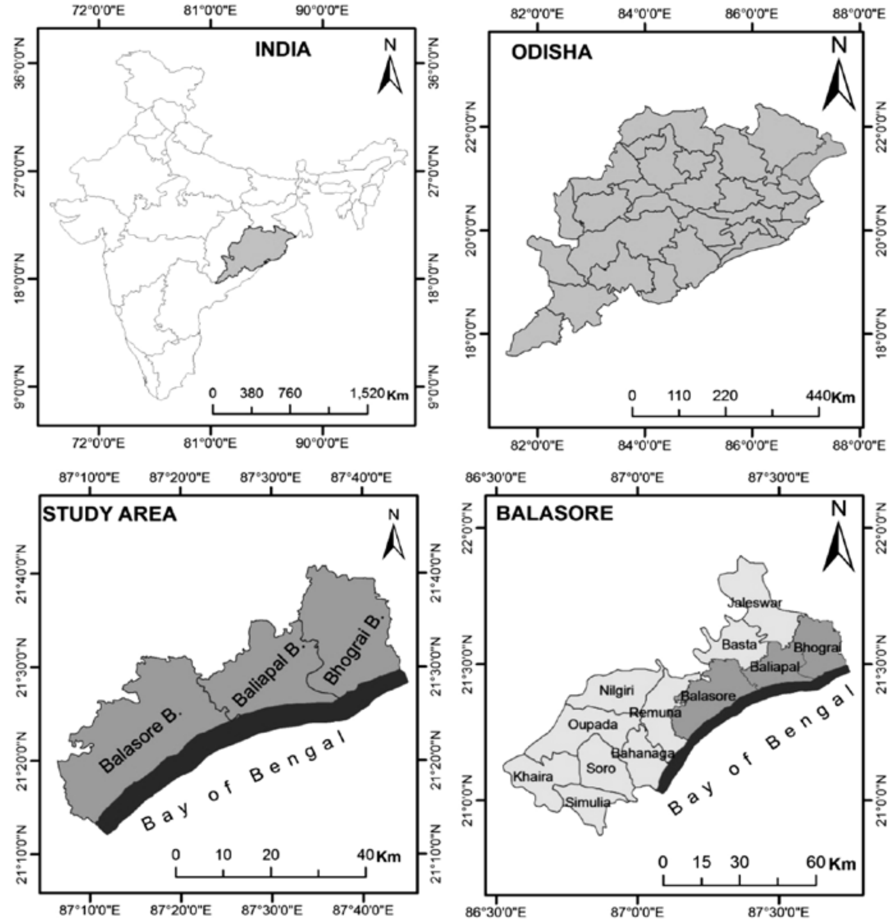

Figure 2. Location map of Balasore district with clockwise direction.

deposits of Holocene to recent origin that were deposited by the Subarnarekha River.

The area has a natural gradient that runs from the east to the southeast direction, which is followed by the Subarnarekha River. The study area is covered mostly by sandy clay and silty loam soils that developed under a brackish environment. The pH of the soil varies between 6.5 and 8.0 (pre-monsoon season) and 6.2 and 8.2 (post-monsoon season). This type of soil has a high water retaining capacity. Climatic variations of the study area are more significant between monsoon and pre-monsoon seasons. The temperature varies from a minimum of 9°C in winter to a maximum of 38°C in summer. Relative humidity ranges between 90% and 96% in most of the months. Low atmospheric pressure is often present during the summer and monsoon periods. Wind dominantly blows in from offshore areas. There is no extensive forestland in the study area and natural vegetation primarily consists of grasses (e.g., Sesuvium portolacrustum and Ipomoea bioloba) and herbs (e.g.,Lantana camara, Acanthaceae, and Calotropis gigantea). Trees like casuarina, eucalyptus, and Acacia auriculiformis have been planted in this area, while coconut, banana, bamboo and mango are indigenous floral species (Barman, Chatterjee and Khan, 2015). Geomorphologically, area is subdivided into two substrates of landform units e.g Subarnarekha delta and chanier plain.

Subarnarekha Delta

Subarnarekha delta plain is situated at the western limit of 'Kanthi coastal plain'. Cuspate arrangement of chenier ridges is a significant feature of the delta around estuaries. There are six successive chenier ridges and four beach ridges within the distance of four and half kilometres from Chandaneswar to Talsari at the eastern flank of the Subarnarekha delta plain (Paul, 1996).All these sand ridges are separated by inner marshlands or the intervening tidal mudflats of different periods. The entire delta plain is enclosed by series of parallel and sub-parallel beach ridges and sand dunes at the seaward side. The Subarnarekha estuary channel is impeded by the growth of beach spits or beach ridges, which cause the channel flow almost parallel to the shore line in the direction of long shore drift for several kilometres at the sea ward end. The actual delta building of the Subarnarekha River starts with the west ward bend of its lower course to meet the Bay of Bengal. The east ward pointed river mouth is now depositing a series of off shore bars only at the eastern side of the delta. As a whole the Subarnarekha delta is asymmetric in its growth. The eastern side of the delta has an extensive growth, in which the chenier ridges and beach ridges are widely separated by tidal flats and mud flats. These intervening low lands range from 2 – 2.5 meters in height from the mean sea level.

Chenier Plain

This type of coastal plain is composed of extensive tidal mud flats with widely separated sub-parallel sandy beach ridges that occur along a 72 km stretch of coast line between the Ganga and Baitarani-Brahmani river mouths. Abandoned supply of sands and fluctuating supply of fine grained sediments produce the prerequisite condition for chenier plain (Otvos and Price, 1979). The 16 km wide chenier plain of the delta has prograded sea ward, since the end of the Holocene transgression with the production of substantial wedge and predominantly fine-grained sediments and abandoned supply of Subarnarekha sand into the coast through major floods. Individual chenier of the delta is up to 10 meters high, 250-1000 meters wide and 22-40 km long on both thesides of the river Subarnarekha.

METHODS AND MATERIALS

Vulnerability refers to the inability (of a system or a unit) to withstand the effects of a hostile environment. Vulnerability is a term, understanding of it is essential to efficient management of risk. Vulnerability analysis is an important stage of risk assessment. Vulnerability is defined as the characteristics of a person or a group, in a particular situation that influences and exposes their limitations, leading to lack of capacity to anticipate, cope with, resist and recover from the impact of natural hazards. Vulnerability is understood as the combination of societal, economic and environmental issues, which give way to the natural hazards to become a disaster. Social characteristics like gender, age, occupation, marital status, race, ethnicity, religion of the people exposed to a hazard determine their loss, injury sufferings, life chances etc. Different types of vulnerability have been recognized by Aysan (1993) viz. economic vulnerability (poor access to resources); social vulnerability (weak social structure and deterioration of social relations); ecological vulnerability (degradation of environmental quality); organizational vulnerability (lack of national and local institution); attitudinal vulnerability (lack of awareness); political vulnerability (lack of political power); cultural vulnerability (some orthodox beliefs and customs) and physical vulnerability (weak buildings and structures). The poorest and marginal people in a society who live with perpetual indebtedness, malnutrition, ill health, unhygienic living environment and violence are highly vulnerable in the face of a hazard. Therefore, any additional stress like loss of land, shelter, occupation, assets caused by hazard place those people in catastrophe. The operational model that helps in assessing risk as well vulnerability is as under.

R = f_1 {Hazard (H), Vulnerability (V), Exposure (Ex)}
V = f_2 {Social (S), Economic (E)}
S = f_3{Poverty (P), Education (Ed), Health quality (Q), Population (P)}
E = f_4 {GDP, Income Level (IL), Indebtedness (ID)}

Information required for vulnerability analysis is summarized in the Table 2. In this study, emphasises is on five groups that are likely to have least protection against hazard. Nature and composition of such highly vulnerable groups may vary from place to place and situation to situation. The disparities among the vulnerable groups in accessing four types of resources (land, water, house/ shelter and transport), in the wake of a disaster event help in assessing socio-economic vulnerability of a particular community. The symbols are used in this study to indicate whether a meticulous group is probably exposed to incident enhanced (+), reduced (-) or unaltered/ no change (0) in circumstances in accessing the possessions. But, the '0's are not well thought-out since they are not considerable with deference to their vulnerability. If the researcher understands that there is actually no change in any variable at the face of hazards then he can put '0' in calculating vulnerability in Table 3.

Obvious that, the data are ordinal scaled and not normally distributed. Hence, one can use the principle of binomial test (as applied in sign test) for determining the probability of positive or negative changes between pre- and post-event situations with respect to each of the selected variables. The probability for the k number of positive (or negative) observations is given by

Probability mass function

In general, if the random variable X follows the binomial distribution with parameters n and p, we write $X \sim B(n, p)$. The probability of getting exactly k successes in n trials is given by the probability mass function (Equation i):

$$f = (k; n, p) = \Pr(X = k) = \binom{n}{k} p^k (1-p)^{n-k} \quad \text{(i)}$$

for k = 0, 1, 2, ..., n, where

$$\binom{n}{k} = \frac{n!}{k!(n-k)!} \quad \text{(ii)}$$

Table 2. The symbols are used to signify whether a particular group is likely to experience enhanced (+), reduced (-) or no change (0) in a situation in accessing the resources. But, the '0's are not considered because they are not significant with respect to vulnerability. If the researcher understands that there is really no change in any variable at the face of hazards then he can put '0' in calculating vulnerability.

Access to	Potential Vulnerable Groups																																		
	Poorest (33%)												Middle (33%)												Richest (33%)											
	Women			Child			Elder			Minority			Women			Child			Elder			Minority			Women			Child			Elder			Minority		
	Respondent's perception in regard to change in condition between pre and post disaster event																																		
Responses'	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0	+	-	0
Land																																				
Water																																				
House/-Shelter																																				
Trans-port																																				

This is the binomial coefficient (Equation ii), hence the name of the distribution. The formula can be understood as follows: we want k successes (p^k) and n − k failures $(1 - p)^{n-k}$. However, the k successes can occur anywhere among the n trials and there are $\binom{n}{k}$ different ways of distributing k successes in a sequence of n trials.

In creating reference tables for binomial distribution probability, usually the table is filled in up to n/2 values. This is because for k > n/2, the probability can be calculated by its complement as (Equation iii)

$$f(k,n,p) = f(n-k,n,1-p). \tag{iii}$$

Looking at the expression f (k, n, p) as a function of k, there is a k value that maximizes it. This k value can be found by calculating (Equation iv)

$$\frac{f(k+1,n,p)}{f(k,n,p)} = \frac{(n-k)p}{(k+1)(1-p)} \tag{iv}$$

and comparing it to 1. There is always an integer M that satisfies (Equation v)

$$(n+1)p - 1 \leq M < (n+1)p. \tag{v}$$

f(k, n, p) is monotone increasing for k < M and monotone decreasing for k > M, with the exception of the case where (n + 1)p is an integer. In this case, there are two values for which f are maximal: (n + 1) p and (n + 1) p − 1. M is the most probable (most likely) outcome of the Bernoulli trials and is called the mode. Note that the probability of it occurring can be fairly small.

Cumulative distribution function

The cumulative distribution function can be expressed as (Equation vi):

$$F(k;n,n) = \Pr(X \leq k) = \sum_{i=0}^{k} \binom{n}{i} p^i (1-p)^{n-i} \tag{vi}$$

Where, $q = (1 - p)$

Where [k] is the "floor" under k, i.e. the greatest integer less than or equal to k. It can also be represented in terms of the regularized incomplete beta function (Equation vii)

$$\begin{aligned} F(k;n,n) &= \Pr(X \leq k) \\ &= I_{1-p}(n-k,k+1) \\ &= (n-k)\binom{n}{k}\int_0^{1-p} t^{n-k-1}(1-t)^k\,dt. \end{aligned} \tag{7}$$

Where n = number of observations, p = 0.05 probability of positive changes and q = 0.5 probability of negative changes. Thus calculated probabilities may be expressed in zero to unity. The test is to be conducted for each of the variables under every resource type and values obtained are to be added to get the vulnerability of a particular group. Vulnerability of the Gram Panchayat can be determined by adding up the product of vulnerability value for the group and their percentage in the total population.

RESULTS

In this study, we investigated how coastal vulnerability and their probability vary across the local GPs in the Balasore district, Odisha. All of the 87 (including Balasore town) GPs in the study area were classified into five categories of a probability of coastal vulnerability (p) and their intimate coastal vulnerability score (CVS), which ranged from a very low vulnerability through intermediate classes to a very high vulnerability in Table 4 and Table 5,respectively. Accordingly, maps were prepared on the basis of the calculated probability of coastal vulnerability (p) and their intimate coastal vulnerability score (CVS), for each of the GPs to visualize the spatial variability of probability of vulnerability and vulnerability score within the block in Figure 3 and Figure 4,respectively. The results

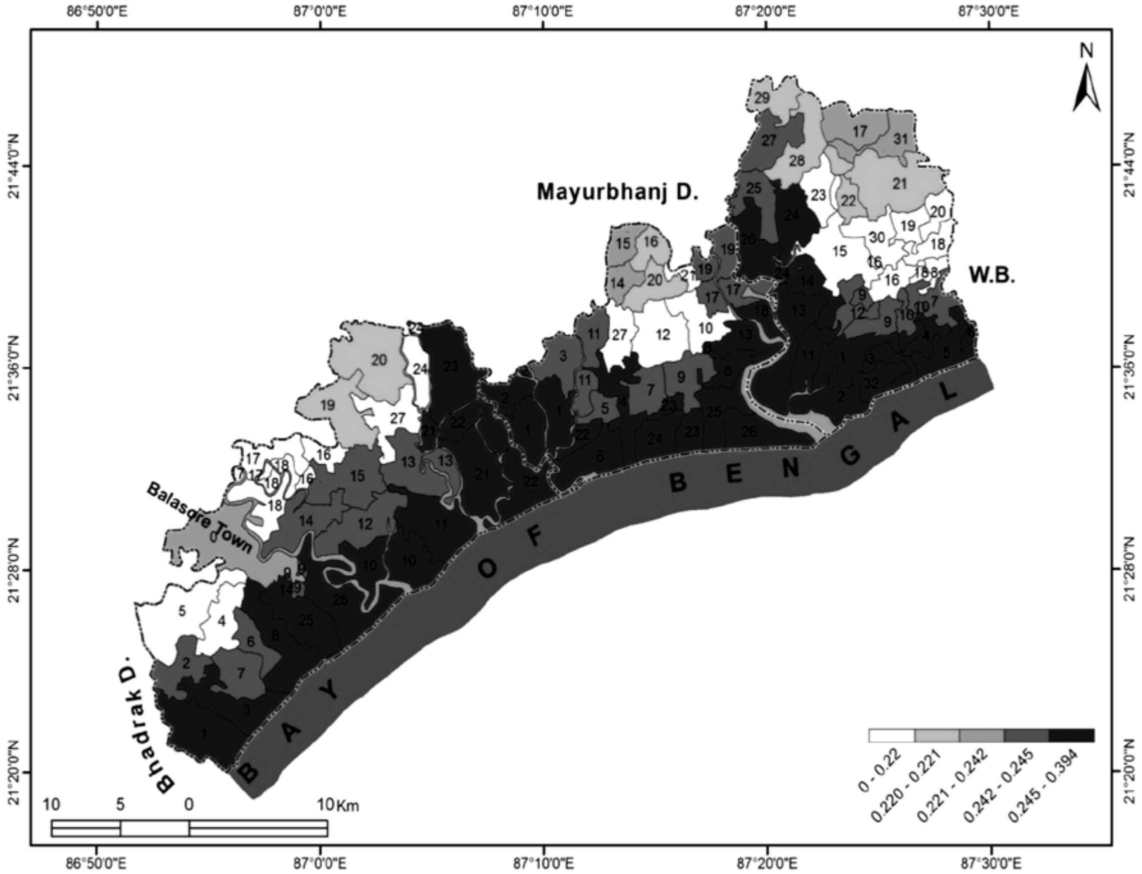

Figure 3. Map of Probability of coastal vulnerability is to be prepared for each of the variables under every resource type and values obtained are to be added to get the Probality of vulnerability of a particular group.

showed that the probability of their associated vulnerability ranges from 0.22-0.39 for entire 87 GPs.From the study Sahuria, Sultanpur, Guneibasana, Mandarsahi, Deula, Analia, Putina and Dehurdha of Bhograi block, Madhupura, Deula, Ghantuai and Balarampur of Baliapal block and Saragaon, Genguti, Odangi, Nagram, Baunla, Rasalpur-II, Kuradiha of Balasore block have been categorised under Very –low probability of coastal vulnerability. In contrast, the Tukurihazra, Narayanmohantipadia, Sharadhapur, Shankaari, Huguli, Bajitpur, Jayarampur, Rasalpur, Bhograi, Kusuda, Kharidpimpal and Kanthi Bhaunri of Bhograi block, Bolonga, Kunduli, Nuagaon, Jambhirai, Badas, Jamkunda, Bishnupur, Panchupali, Betagadia, Anladiha, Dagra and Choumukhaof Baliapal block and Rasalpur-I, Joydebkasba, Ranasahi, Parikhi, Bahabalpur, Sartha, Kashaphala, Srirampur, Hidigaon and Srikona of Balasore block have been categorised under Very high probability of coastal vulnerability. Remaining GPs have been placed under intermediate classes according to their probability value of vulnerability.

The present study therefore is an endeavour to develop a probability of coastal vulnerability (p) and their intimate coastal vulnerability score (CVS) for the maritime Balasore district of Odisha using land, water, house/shelter and transport resources. Most of these parameters are dynamic in nature and require a large amount of data from different sources.

In this veneration, only Balasore town is prone to experience high order of adverse impact due to various hazards, as suggested by very high vulnerability score.

In contrast, Sahuria, Barbatia, Gopinathpur, Analia, Baunsadiha, Putina, Nahara and Balim of Bhograi block, Ratei, Balikuti, Deula, Srirampurmahakumaremu, Kumbhari Nikhira, Baliapal, Ghantuai and Balarampurof Baliapal block and Sashanga, Saragaon, Gudu, Padmapuri, Patrapada, Gopinathpur, Odangi, Nagram, Baunla, Rasalpur-II and Kuradiha of Balasore block are prone to limited adverse impacts as indicated by Very low vulnerability scores. Rest of the blocks(GPs) are split intointermediate classes, according to their vulnerability scores.

The present study also showed that some of the GPs like Sahuria, Sultanpur, Guneibasana, Mandarsahi, Deula, Analia, Putina and Dehurdha of Bhograi block, Madhupura, Deula, Ghantuai and Balarampur of Baliapal block and Saragaon, Genguti, Odangi, Nagram, Baunla,

Table 3. The calculated probabilities expressed in zero to unity. The binomial test is to be conducted for each of the variables under every resource type and values obtained are to be added to get the Probability of vulnerability of a particular group. Vulnerability score of the Grampanchayat can be determined by adding up the product of probability of vulnerability for the group and their total population.

Block	G.P Code	Observation Station , G.P	Total Population	Probability of Vulnerability	Coastal Vulnerability Score
Bhograi	1	Tukurihazra	7706	0.394687	3041.458022
	2	Narayanmohantipadia	5571	0.394687	2198.801277
	3	Sharadhapur	7622	0.394687	3008.304314
	4	Shankaari	10108	0.394687	3989.496196
	5	Huguli	10003	0.394687	3948.054061
	6	Bajitpur	6380	0.394687	2518.10306
	7	Kakhada	9654	0.245436	2369.439144
	8	Sahuria	5489	0.22097	1212.90433
	9	Nimatpur	7641	0.245436	1875.376476
	10	Barbatia	4812	0.245436	1181.038032
	11	Jayarampur	8516	0.394687	3361.154492
	12	Gopinathpur	5197	0.245436	1275.530892
	13	Rasalpur	6875	0.394687	2713.473125
	14	Bhograi	9935	0.394687	3921.215345
	15	Sultanpur	9162	0.22097	2024.52714
	16	Guneibasana	8696	0.22097	1921.55512
	17	Dehunda	7540	0.24246	1828.1484
	18	Mandarsahi	9463	0.22097	2091.03911
	19	Deula	7317	0.22097	1616.83749
	20	Analia	5848	0.22097	1292.23256
	21	Mahagab	11531	0.221121	2549.746251
	22	Baunsadiha	6437	0.221121	1423.355877
	23	Putina	5990	0.22097	1323.6103
	24	Kusuda	8975	0.394687	3542.315825
	25	Nachinda	8484	0.245436	2082.279024
	26	Kharidpimpal	10504	0.394687	4145.792248
	27	Nahara	4615	0.245436	1132.68714
	28	Kashabakamarddha	11327	0.221121	2504.637567
	29	Balim	4389	0.221121	970.500069
	30	Dehurdha	12407	0.22097	2741.57479
	31	Gunasartha	7202	0.24246	1746.19692
	32	Kanthi Bhaunri	5560	0.394687	2194.45972

Baliapal	1	Bolonga	7720	0.394687	3046.98364
	2	Kunduli	8092	0.394687	3193.807204
	3	Baniadiha	6986	0.245436	1714.615896
	4	Nuagaon	5251	0.394687	2072.501437
	5	Ratei	4941	0.245436	1212.699276
	6	Jambhirai	6807	0.394687	2686.634409
	7	Jagajipur	8055	0.245436	1976.98698
	8	Badas	7999	0.394687	3157.101313
	9	Pratappur	6728	0.245436	1651.293408
	10	Madhupura	8409	0.22097	1858.13673
	11	Balikuti	6068	0.245436	1489.305648
	12	Deula	6880	0.22097	1520.2736
	13	Jamkunda	8730	0.394687	3445.61751
	14	Srirampur Mahakumaremu	4900	0.24246	1188.054
	15	Kumbhari	3915	0.24246	949.2309
	16	Nikhira	6232	0.221121	1378.026072
	17	Baliapal	5999	0.245436	1472.370564
	18	Bishnupur Mahakumanayabali	6264	0.394687	2472.319368
	19	Asti	7517	0.245436	1844.942412
	20	Debhoga	7446	0.221121	1646.466966
	21	Ghantuai	4040	0.22097	892.7188
	22	Panchupali	4926	0.394687	1944.228162
	23	Betagadia	6859	0.394687	2707.158133
	24	Anladiha	6742	0.394687	2660.979754
	25	Dagra	6629	0.394687	2616.380123
	26	Choumukha	7155	0.394687	2823.985485
	27	Balarampur	3982	0.22097	879.90254
Balasore	1	Rasalpur 1	7973	0.394687	3146.839451
	2	Sashanga	4302	0.245436	1055.865672
	3	Joydebkasba	8717	0.394687	3440.486579
	4	Saragaon	5609	0.22097	1239.42073
	5	Genguti	9265	0.22097	2047.28705
	6	Gudu	699	0.245436	171.559764
	7	Padmapuri	4904	0.245436	1203.618144
	8	Ranasahi	6908	0.394687	2726.497796
	9	Patrapada	619	0.245436	151.924884
	10	Parikhi	11349	0.394687	4479.302763
	11	Bahabalpur	10650	0.394687	4203.41655
	12	Gopinathpur	5814	0.245436	1426.964904
	13	Chhanua	7697	0.245436	1889.120892
	14	Sindhia	10450	0.245436	2564.8062
	15	Olanda Saragaon	8088	0.245436	1985.086368
	16	Odangi	4348	0.22097	960.77756
	17	Nagram	6769	0.22097	1495.74593
	18	Baunla	6013	0.22097	1328.69261
	19	Haldipada	9034	0.221121	1997.607114
	20	Kasipada	13158	0.221121	2909.510118
	21	Sartha	15900	0.394687	6275.5233
	22	Kashaphala	10301	0.394687	4065.670787
	23	Srirampur	7850	0.394687	3098.29295
	24	Rasalpur 2	4801	0.22097	1060.87697
	25	Hidigaon	6113	0.394687	2412.721631
	26	Srikona	12118	0.394687	4782.817066
	27	Kuradiha	4748	0.22097	1049.16556
		Balasore Town	66986	0.24246	16241.42556

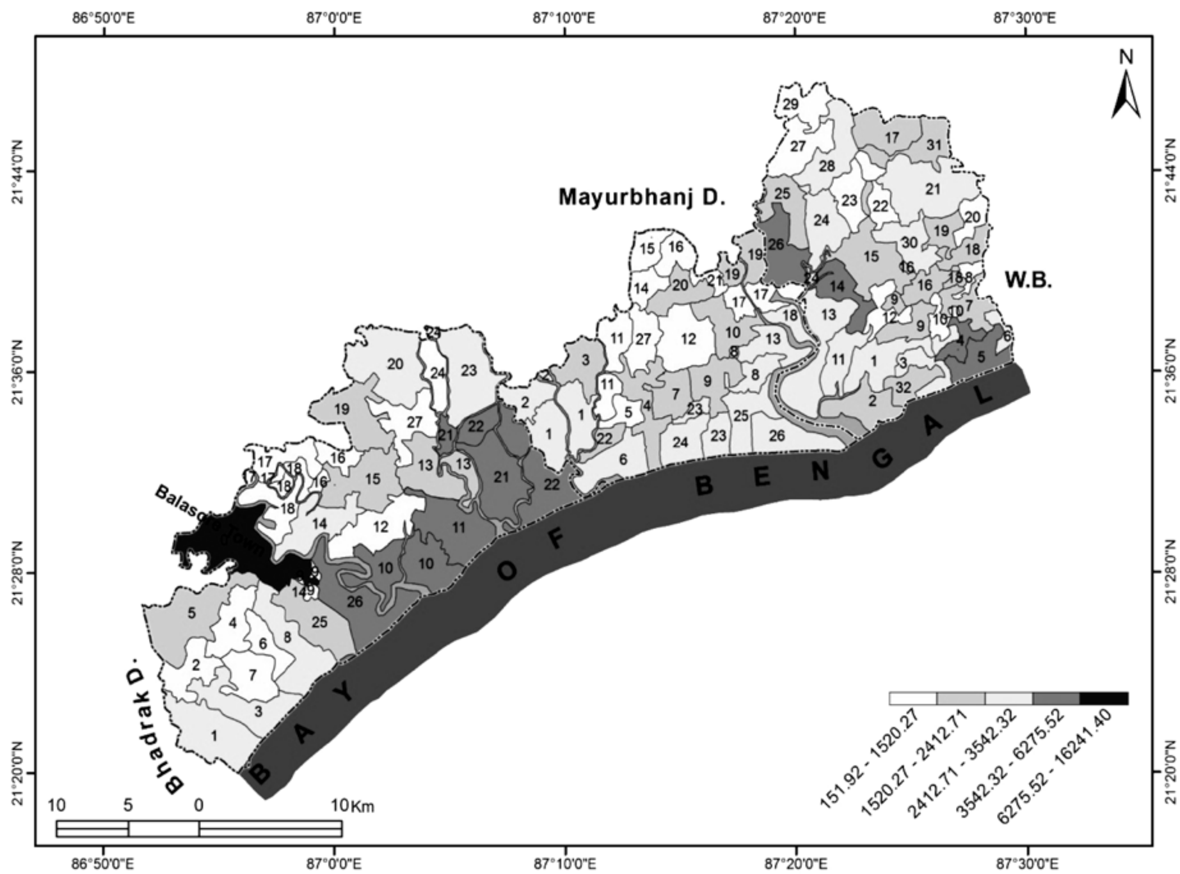

Figure 4. Map of coastal Vulnerability score of the Grampanchayat can be determined by adding up the product of probability of vulnerability for the group and their total population.

Rasalpur-II, Kuradiha of Balasore block in spite of very high probability of associated vulnerability (as per calculated details) may not experience high negative impact as population density is limited and probability of this factor reaching higher vulnerable levels is less probable. In case of Balasore town, having the moderate or intermediate probability of its associated vulnerability, it is categorised as high vulnerability segment that can experience high level of negative impact due to population density and other negative factors. From these details it is evident that highly populated GPs are more vulnerable compared to less populate.

It is interesting to note that, despite being located far away from the sea, the Bhograi and Kharidpimpal GPs of Bhograi block had high probability of coastal vulnerability (p) and their intimate coastal vulnerability score (CVS) also high.

The GPs classified under low and very low probability of coastal vulnerability (p) and their intimate coastal vulnerability score (CVS) experienced low intensity and low magnitude vulnerable episodes during river flooding in monsoon period and duration of flood water inundation was also not affect these areas considerably only due to its less population. According to respondents, the land, house/shelter and transport system damage intensities of pre and post hazard events were very high in the coastal facing GPs and the GPs, located along the river bank, because these regions were mostly used for the purpose of agriculture and aquaculture practices. Settlements near these areas are located on the top of the back barrier dune to escape the frequent flooding. Conversely, the coastal GPs with interior settlement locations mostly suffered from drinking water and road damage because this area is densely populated.

DISCUSSION

Geomorphologically and ecologically, the study area belongs to the Subarnarekha delta Chenier plain located along the eastern and western banks of the Subarnarekha River. The area is represented by regressive younger back beach ridges, and open land ward mudflats and floodplains. The low lying zones are in general covered by agricultural fields. The southernmost seafront part of the Balasore district has a natural seashore beach barrier.

Balasore district is dominantly a part of the Subarnarekha flood plain. The area is naturally sculpted with westward avulsion of the river and features developed through exchanges among marine transgression processes.

Table 4. Grampanchayat wise occurrences of Probability of coastal vulnerability with their assigned attribute assemblage into five classes.

Probability of Vulnerability occurence	Assigned attribute	Block	G.P code	Identified G.P
0-0.22	Very Low	Bhograi	1, 2, 3, 4, 5, 6, 11, 13, 14, 24, 26, 32	Tukurihazra, Narayanmohantipadia, Sharadhapur, Shankaari, Huguli, Bajitpur, Jayarampur, Rasalpur, Bhograi, Kusuda, Kharidpimpal, Kanthi Bhaunri
		Baliapal	1, 2, 4, 6, 8, 13, 18, 22, 23, 24, 25, 26	Bolonga, Kunduli, Nuagaon, Jambhirai, Badas, Jamkunda, Bishnupur, Panchupali, Betagadia, Anladiha, Dagra, Choumukha
		Balasore	1, 3, 8, 10, 11, 21, 22, 23, 25, 26	Rasalpur 1, Joydebkasba, Ranasahi, Parikhi, Bahabalpur, Sartha, Kashaphala, Srirampur, Hidigaon, Srikona
0.22-0.221	Low	Bhograi	7, 9, 10, 12, 25, 27	Kakhada, Nimatpur, Barbatia, Gopinathpur, Nachinda, Nahara
		Baliapal	3, 5, 7, 9, 11, 17, 19	Baniadiha, Ratei, Jagajipur, Pratappur, Balikuti, Baliapal, Asti
		Balasore	2, 6, 7, 9, 12, 13, 14, 15	Sashanga, Gudu, Padmapuri, Patrapada, Gopinathpur, Chhanua, Sindhia, Olanda Saragaon
0.221-0.242	Moderate	Bhograi	17, 31	Dehunda, Gunasartha
		Baliapal	14, 15	Srirampur Mahakumaremu, Kumbhari
		Balasore	Balasore town	Balasore town
0.242-0.245	High	Bhograi	21, 22, 28, 29	Mahagab, Baunsadiha, Kashabakamarddha, Balim
		Baliapal	16, 20	Nikhira, Debhoga
		Balasore	19, 20	Haldipada, Kasipada
0.245-0.394	Very High	Bhograi	8, 15, 16, 18, 19, 20, 23, 30	Sahuria, Sultanpur, Guneibasana, Mandarsahi, Deula, Analia, Putina, Dehurdha
		Baliapal	10, 12, 21, 27	Madhupura, Deula, Ghantuai, Balarampur
		Balasore	4, 5, 16, 17, 18, 24, 27	Saragaon, Genguti, Odangi, Nagram, Baunla, Rasalpur 2, Kuradiha

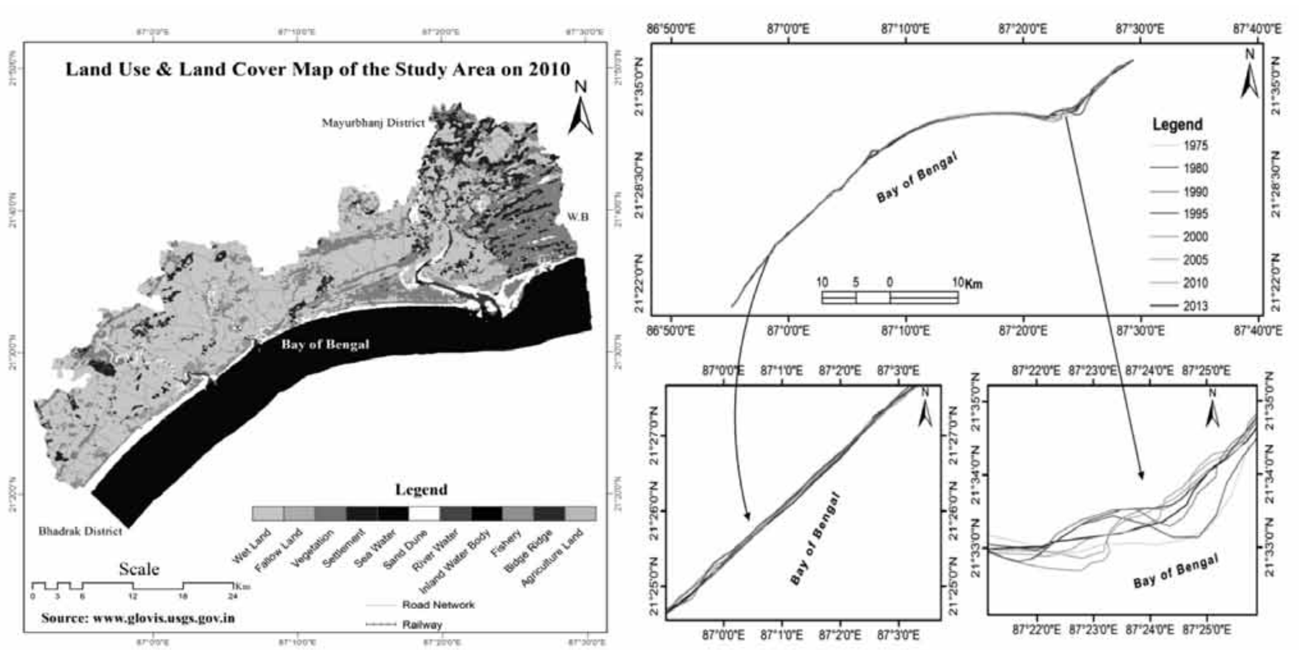

Figure 5. Shoreline position at different years from fixed base along same crenulations of shore line and the morphological features of study area.

Table 5. Grampanchayat (GPs)wise distribution of coastal vulnerability scores (CVS) with their assigned attribute assemblage into five classes.

Coastal Vulnerability Score (CVS)	Assigned attribute	Block	G.P code	Identified G.P
151.92-1520.27	Very Low	Bhograi	8, 10, 12, 20, 22, 23, 27, 29	Sahuria, Barbatia, Gopinathpur, Analia, Baunsadiha, Putina, Nahara, Balim
		Baliapal	5, 11, 12, 14, 15, 16, 17, 21, 27	Ratei, Balikuti, Deula, Srirampurmahakumaremu, Kumbhari, Nikhira, Baliapal, Ghantuai, Balarampur
		Balasore	2, 4, 6, 7, 9, 12, 16, 17, 18, 24, 27	Sashanga, Saragaon, Gudu, Padmapuri, Patrapada, Gopinathpur, Odangi, Nagram, Baunla, Rasalpur 2, Kuradiha
1520.27-2412.71	Low	Bhograi	2, 7, 9, 15, 16, 17, 18, 19, 25, 31, 32,	Narayanmohantipadia, Kakhada, Nimatpur, Sultanpur, Guneibasana, Dehunda, Mandarsahi, Deula, Nachinda, Gunasartha, Kanthi Bhaunri
		Baliapal	3, 4, 7, 9, 10, 19, 20, 22	Baniadiha, Nuagaon, Jagajipur, Pratappur, Madhupura, Asti, Debhoga, Panchupali
		Balasore	5, 13, 15, 19, 25	Genguti, Chhanua, Olanda Saragaon, Haldipada, Hidigaon
2412.71-3542.32	Moderate	Bhograi	1, 3, 6, 11, 13, 21, 24, 28, 30	Tukurihazra, Sharadhapur, Bajitpur, Jayarampur, Rasalpur, Mahagab, Kusuda, Kashabakamarddha, Dehurdha
		Baliapal	1, 2, 6, 8, 13, 18, 23, 24, 25, 26	Bolonga, Kunduli, Jambhirai, Badas, Jamkunda, Bishnupur, Betagadia, Anladiha, Dagra, Choumukha
		Balasore	1, 3, 8, 14, 20, 23	Rasalpur 1, Joydebkasba, Ranasahi, Sindhia, Kasipada, Srirampur
3542.32-6275.52	High	Bhograi	4, 5, 14, 26	Shankaari, Huguli, Bhograi, Kharidpimpal
		Baliapal		NA
		Balasore	10, 11, 21, 22, 26	Parikhi, Bahabalpur, Sartha, Kashaphala, Srikona
6275.52-16241.40	Very High	Bhograi		NA*
		Baliapal		NA*
		Balasore	Balasore town	Balasore town

NA*=Not Available

Enormous supplies of sediments and predominant wave-tide dynamics were basically responsible for the development of sandy flat and dreary zones. The area is delimited by the Subarnarekha River in the east, the young chenier complex to the west and north and the beach barrier complex and wash over deposits to the south.

The geomorphological signatures like river bank erosion, shoreline erosion and frequent shoreline change Figure 5 in the region suggest that this coastal area has probably started to experience a phase of marine transgression. The frequency and intensity of cyclones have increased to a certain extent. Cyclone-induced storm surges and torrential rains in the upper catchment of the Subarnarekha River have been responsible for storm induced flooding in the study area. In addition, the intensity and severity of the coastal hazards seem to have increased possibly due to recent weather and climate related aberrations and environmental changes. The Subarnarekha, Dugdugi and Burahbalam rivers carry large volumes of discharge loaded with enormous quantities of sediment. These discharges seem to be contributing to some ongoing geomorphological changes Figure 6.

These discharge flows receive resistance to their drainage from a number of factors including the strong southwesterly monsoon wind and resultant cross-shore currents, tidal waves and high magnitude tidal inflows. These natural phenomena cause the accumulation of large amounts of water at and near the mouth of the Subarnarekha, Dugdugi and Burahbalam rivers respectively, causing flooding at the sea front GPs of the study area. Moreover, this area is only 0.5-1m above sea level, which makes the area more vulnerable to flooding and cyclone induced storm surge as well as beach ridge breaching. The landward margin of the studied blocks is characterized by an intricate network of tidal inlets along which sea water can enter into the nearby GPs and cause flood during the peak monsoon phase and cyclones. These GPs are to a considerable extent are exposed to the sea, with

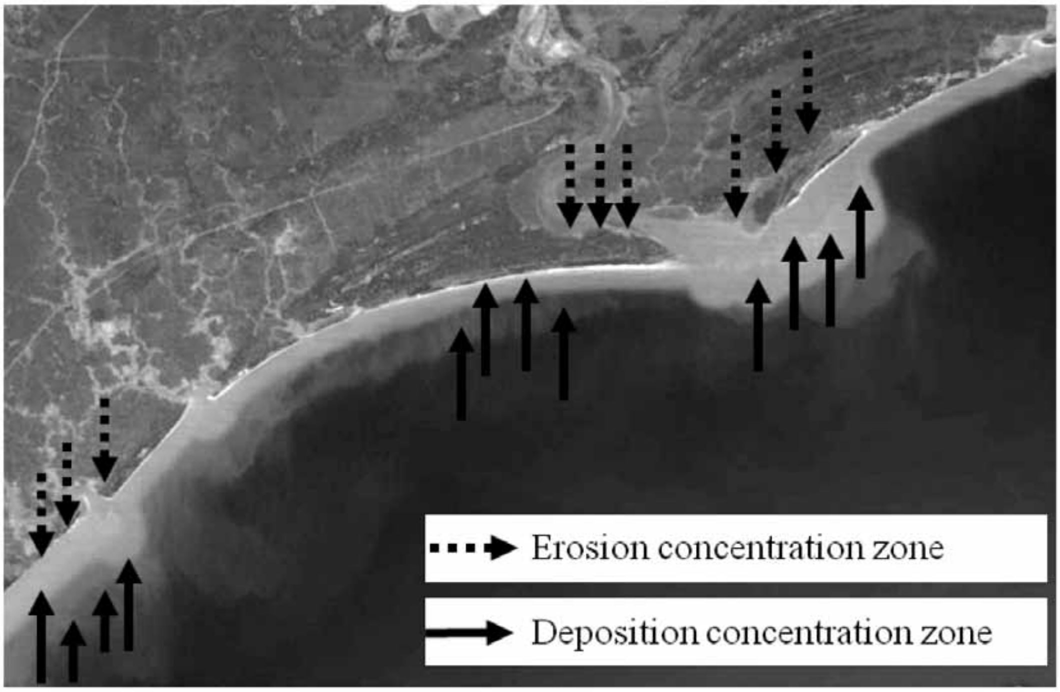

Figure 6. Satellite view depicts that erosion is mainly taking place at the centre of the vortex and also at the near shore region where as the accretion is taking place at the vortex boundary and also at the offshore region.

only scrappy sand dunes acting as barriers. An earthen embankment was built to protect the Narayanmohantiparia GP of Bhograi block from flood hazards. This got completely washed away by episodic strong sea waves. Only remnants of its basement can be found in a few places on the beach. Due to ill organized Land use operations good cover of mangroves got converted in to sparse mangrove swamps. Land use patterns in the area have also undergone recent changes that have increased. Operations have resulted in more barren patches that are devoid of any natural barriers. The coastal facing GPs with estuarine locations are being flooded in two different ways.

The first is due to the spilling of the said rivers (sweet water flood) and the second is caused by coastal flooding (saline flood) from high magnitude waves or storm surges. Moreover, these GPs except Narayanmohantiparia and Sharadhapur of Bhograi block are densely populated mainly owing to people here have easy access to marine resources, which the coastal dwellers utilize for their livelihood.

Therefore, hazard resultant damages in those GPs are usually very high even in the event of moderate intensity floods.

Bhograi and Kharidpimpal GPs of Bhograi block that have high vulnerability score are located along the western bank of the Subarnarekha River where the river follows along meandering course. Because of the high degree of sinuosity in the estuarine section of the Subarnarekha, the gradient flows of river discharge in this location can become easily obstructed during the monsoon season. Torrential rainfall in the expansive catchment area also contributes to a large volume of discharge that can fail to drain seamlessly. As such, this river often spills over during the rainy season and causes riverine flooding in these two GPs. Moreover, flooding problems are exacerbated during high tides, when considerable volumes of ocean water ingress through the funnel shaped estuary of the Subarnarekha River. During these times, the corresponding tidal bore acts to restrict river discharge that would otherwise be drained into the sea. As a consequence, water levels in the river valley frequently become high enough to spill over the banks and cause flood problems. At the mouth of the river, the width of the Subarnarekha is about 1312.5m. The width of the river reduces to 750m at a distance of 1875m landward from its mouth and the width of the river valley is only 375m near Bhograi. Hence, the funneling effect of tidal water as it enters into the estuary is a major cause of flooding in Bhograi. On many occasions, this type of flood situation has been accentuated by the release of flood water from the Chandil reservoir.

Land use alteration in the studied blocks is likely responsible for frequent flooding in the area. Aquaculture has recently emerged as a profitable economic activity. Hence, vast stretches of land have been converted to fish farms. High earthen embankments have been constructed around the fish ponds that restrict the spread of flood water over the flood plain; this has caused the flooding situation to become more severe. River engineering in the form of embankment construction along both banks of the Subarnarekha and other rivers have also changed the hydro-geomorphological conditions in this region. These river embankments restrict sedimentation to within the area between the banks and leave no extent for sediments to distribute over the floodplain. Ultimately, this has reduced the capacity of the river valley to retain flood water and has resulted in large deposits of sediment near the river mouth, which has caused a gradual narrowing of the channel.

CONCLUSION

The Balasore district in Odisha, India, consists of 87 GPs that are located on the coastline and the banks of the Subarnarekha, Dugdugi and Burahbalam rivers. This stretch is geomorphologically susceptible to coastal hazards, including cyclones, storm surges and associated natural hazards. Spatial changeability of coastal vulnerability among the GPs was assessed quantitatively by considering both the probability of vulnerability and density of populations of concerned GPs.

The analysis clearly demonstrated that the GPs located along the river bank and those exposed to the sea because of the lack of natural barriers have very high probability of vulnerability, whereas GPs in interior locations are generally in zones of lower probability of vulnerability. The gradual decline in the capacity of the Subarnarekha, Dugdugi and Burahbalam rivers to hold large volumes of water mass received from high-magnitude storm events has augmented this vulnerability. The situation has become critical during monsoons when the inflow of tidal water along the river channel raises the water levels. Storm surges during cyclonic episodes and high tides also lead to the build- up of ocean water that can enter the area along tidal inlets. The last two processes were responsible for exacerbating floods in the past in many of the GPs under study. Moreover, embankments used in aquaculture around fish ponds may be responsible for intensifying the severity of the coastal hazards as well as vulnerability. Variation was also observed among the GPs with respect to the probability of vulnerability. The results from this study show that having the high probability of vulnerability of some GPs, their vulnerability score is lower only owing to its less population.

Overall, the essence of this work lies in the fact that it explores the cause and consequences of coastal vulnerability in a quantitative manner through the use of probability of vulnerability and density of population. In addition, this study was done at a convincingly small spatial scale (GPs wise), where it may be feasible to put into practice coastal vulnerability lessening programs. Specifically, the results from this study may help environmental managers to better understand coastal vulnerability in different GPs of the Balasore districtof Odisha, India. Notably, the probability of vulnerability of pre and post events in terms of changes in said four resources does not always linearly dependent on the physical severity of the coastal extreme events. As such, the results from this study may be helpful for identifying factors that improve resilience and can be incorporated into future planning decisions for coastal vulnerability management. It is opined that if this type of study is carried out for other coastal districts at block level, it would be possible to prepare more comprehensive coastal vulnerability maps that can help in better assessment of the risks associated with coastal vulnerability.

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