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Quantification of Panchayat-Level Flood Risks in the Bhograi Coastal Block, Odisha, India

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ABSTRACT

This paper assesses coastal flood risks through quantification of flood intensity and impacts across the different local Gram Panchayats (GPs) in the Bhograi block, Odisha, India. With respect to the June 2008 flood event in the region, the enormity of flooding was calculated for each GP using normalized values of measurable parameters relating to flood characteristics. Thus, a Flood Magnitude Rank (FMR) was assigned to each of the GPs according to the degree of flooding intensity. Similarly a Flood Impact Rank (FIR) for each GP was derived from a damage database. The product of the FMR and FIR was used to calculate the Flood Severity Score (FSS) for the concerned GPs, which was then multiplied by the probability of flood event occurrences to obtain a Flood Hazard Score (FHS). This analysis was used to divide the study area into five Flood Hazard Risk zones including (a) very low risk (FHS <1.33); (b) low risk (FHS 1.33–2.07); (c) moderate risk (FHS 2.07–3.02); (d) high risk (FHS 3.02–4.90); and (e) very high risk (FHS >4.90) areas. Narayanmohantiparia, Rasalpur and Kharidpimpal fell into the very high flood hazard risk class, whereas Dehunda, Baunsadiha and Balim tended to be at very low risk from flood hazards. The other 26 GPs in the study area were categorized into low- moderate or high risk zones according to their FHS. Overall, this type of flood hazard risk assessment may prove useful for future environmental planning and management programs in coastal regions.

INTRODUCTION

Coastal areas represent zones of interaction between marine and terrestrial systems and they are exposed to a variety of land and sea based hazards including those that originate from storms, flooding and erosion. The diversity of coastal areas in terms of ecosystems, landforms and land uses makes their response to hazards highly complex and some coastal areas may be particularly sensitive to damage. In the context of the growing importance of coastal zones due to their high ecosystem productivity, increasing population sizes, increasing industrial development, more intensive resource exploitation and expanding recreational activities concerns about coastal hazards have increased in recent years and there is a clear need for effective coastal management programs to help reduce the impacts of disaster events. The Swaminathan committee (The M.S. Swaminathan Committee Report 2006) has recommended vulnerability as an important characteristic to consider in coastal zone management. Assessment of the physical sensitivity and exposure of coasts to hazards is an essential component for any comprehensive coastal vulnerability study. During the last few decades a plethora of literature on coastal risk assessment methods has been published as a consequence of the recognition that global climate change and the resultant rise in sea levels pose real threats to coastal habitats and communities.

The coastal zone management subgroup (CZMS) of the Intergovernmental Panel on Climate Change (IPCC) developed a Common Methodology (CM) involving seven steps that has been employed to assess the vulnerability of various coastal nations to predicted sea level rise (IPCC–CZMS 1992). This method considers probable impacts of global sea level rise on populations, economic sectors, social assets and agricultural production. However, the data necessary to evaluate one or more parameters using this methodology are often inadequate or not easily available (Klein and Nicholls, 1999).

Kay and Waterman (1993) developed a four-step methodology to overcome limitations associated with the Common Methodologies of IPCC. The four stages include a study of the physical, biological and environmental components of the area under consideration; identification of vulnerable physical, biological, and cultural systems; an assessment of links between the different parts of the study area and finally, formulation of a risk reduction management strategy. This method was criticized by Harvey et al. (1999) on the grounds that techniques used for the physical, biological and environmental studies were poorly defined and that human-induced coastal hazards were not properly considered. Harvey and his colleagues developed an eight-step methodology in which the above discrepancies were removed. Another important contribution in this regard came from Gornitz et al. (2001) and their work incorporates parameters like relief, rock type, landform, tectonics and shoreline shift for calculating

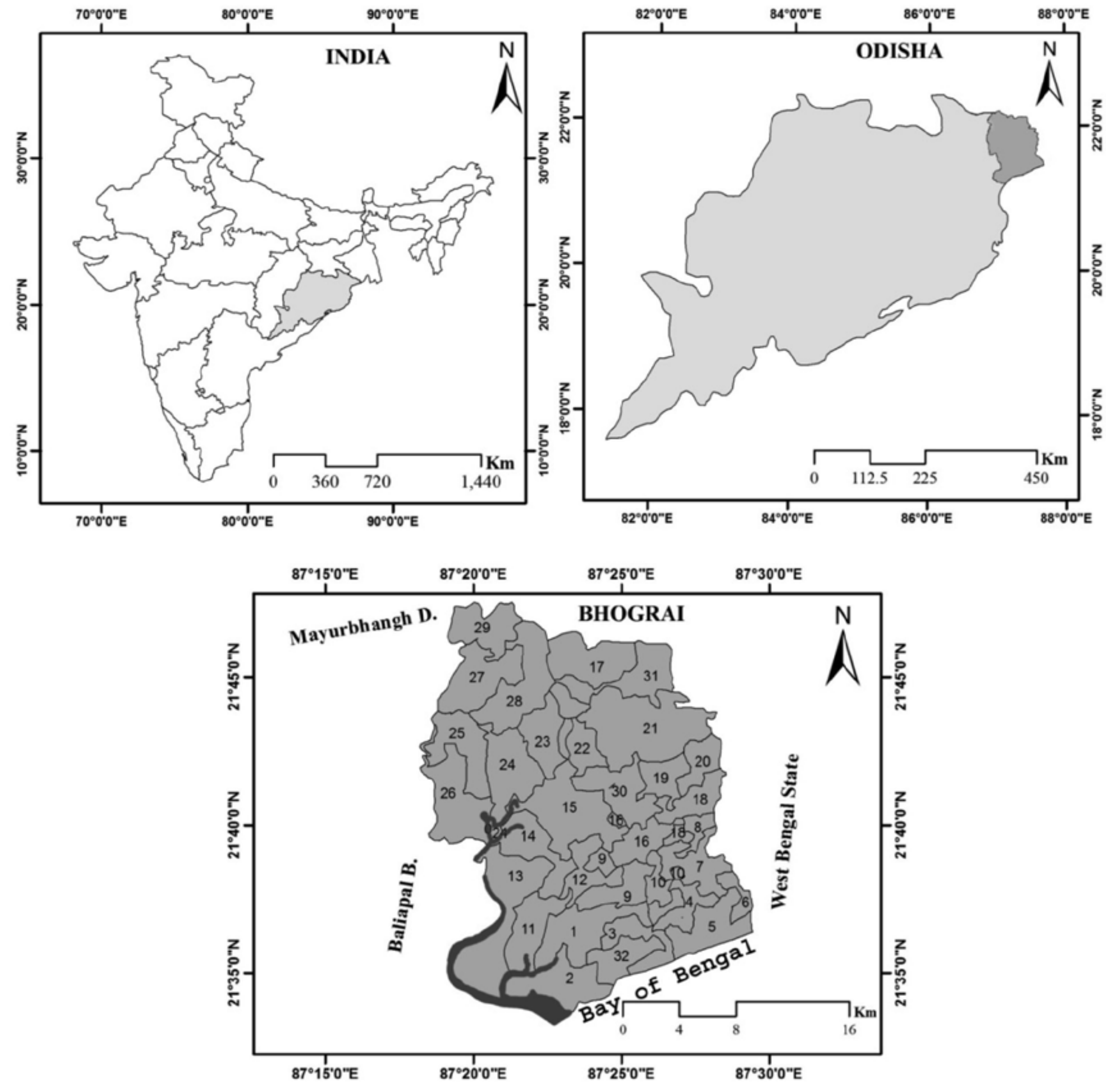

Figure 1. Situated between the Subarnarekha River and Talsari channel, the Bhograi block in Odisha, India constitutes part of the Subarnarekha strand plain; it is exposed to a variety of hazards that originate from both land and sea.

a Coastal Vulnerability Index (CVI). This method has been employed by the United States Geological Survey (USGS) to map the vulnerability of coastal zones in North America. However, a lack of consideration for socio-economic factors has been logically criticized (Abuodha and Woodroffe 2010, Kumar et al., 2010, Shaw et al., 1998). Any assessment of coastal vulnerability without reference to social factors is not very useful (Klein and Nicholls 1999). Accordingly a Social Vulnerability Index (SVI) (Cutter et al., 2003) and the CVI were combined to form a Coastal Social Vulnerability Index (CSoVI) where poverty, population, development, ethnicity, age and urbanization were emphasized along with the physical parameters (Boruff et al., 2005). Furthermore, exposure of a place to physical hazards has been measured in terms of a Place Vulnerability Index (PVI) (Cutter 1996).

STUDY AREA

In the coastal parts of the state of Odisha, India, flood hazards are generally caused by tropical cyclones and very rarely by tsunamis. The degree of flooding largely depends upon the scale of the storm, the height of the storm surge and the tide level at the time of the event. Global sea level rise will be an increasingly important factor to consider if predicted rises in sea level do occur. With sea level rise, river estuaries could experience severe estuarine flooding from the combined effects of storm surges and river floods caused by rainstorms inland. Coastal flooding is the most severe hazard facing many coastal communities around the Bay of Bengal.

The area under study in this paper constitutes part of the alluvium 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 87°17'45"E to 87°29'37"E and 21°30'25"N to 21°47'55"N (Fig.1). 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 2.5m to 3.5m above Mean Sea Level (MSL). Geologically, the area is characterized by ordinary alluvium deposits of Holocene to recent origin that were brought down 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 between 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% – 96% in most months. Low atmospheric pressure is often present during the summer and monsoon period. 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, Acanthaceaesp and Calotropis gigantea). Trees such as casuarina, eucalyptus and Acacia auriculiformis have been planted in this area while coconut, banana, bamboo and mango are indigenous floral species.

METHODS

The assessment of flood hazards included characterization of the flooding in terms of depth, duration of inundated conditions, spatial extent and water velocity. Furthermore, the height of the storm surge in low-lying coastal areas is another important criterion for evaluating flood hazards. Damage to human life, property and infrastructure caused by flood hazards represents other easily measurable components of flood hazard intensity. Field data sheets were prepared in a format appropriate for generating a database for the flood intensity assessment. A substantial number of samples within the study area were collected for each local Gram Panchayat (GP).

MATERIALS

The present study is based on both primary and secondary data. Primary data were collected through intensive field surveys using pre-designed questionnaires at randomly sampled households that represent the various GPs. GP-wise secondary data were collected from the different administrative offices throughout Bhograi block of the Balasore district, Odisha, India (Table 1).

This study used GPs as the spatial unit for analysis. A GP is the smallest administrative unit for which a disaster damage database is maintained and variations in

Table 1. Gram Panchayat (GP) wise secondary data collected from the different administrative offices throughout Bhograi block of the Balasore district, Odisha.

Parameters	Data Used	Data Sources
Flood Hazard intensity	Percentage of Fully Damaged Houses	District Disaster Management Plan, 2001-12
	Percentage of Partly Damaged Houses	District Collector Office (Natural Calamities Cell), 2012
	Number of Population Died	Grampanchayat Office, 2009
	Number of Animal Died	Animal Husbandry Statistical Handbook, 2012
	Monetary Equivalent of Crop Damaged per Hector of Net Cropped Area	Orissa Agricultural Statistics, 2008-2009
	Monetary Equivalent of Fishery Damaged as a Percentage of the Total Value of Fish Production	Office of The District Fishery Officer-Cum-CEOFFDA and BFDA, Balasore, 2010
	Length of Road Damaged as a Percentage of the total Length of the Roads in the Gram Panchayat	Comprehensive district annual plan, Balasore, 2011-12
Flood Hazard Magnitude	Depth of Flood in meter	District Collector Office (Natural Calamities Cell), 2012
	Flood Velocity in meter/Sec.	
	Percentage of Area Under Inundation	Grampanchayat Office, 2012
	Land ward Extension from the Sea Shore	

flooding characteristics are not expected below this scale of geography when the natural terrain under study is considered. Moreover, the socio-economic and demographic features of the population exhibit an acceptable degree of homogeneity at the GP level.

DATA ANALYSIS

To estimate the Flood Magnitude Rank (FMR) of a GP, four parameters were considered, namely, depth of flood, flood velocity, percentage of area under inundation and distance from the seashore. In contrast, seven indicators were selected to enumerate the Flood Impact Rank (FIR) for a GP. These indicators included percentage of fully damaged houses, percentage of partly damaged houses, number of human deaths per thousand people, number of animal deaths per thousand cattle, monetary equivalent of crop damage per hector of net cropped area, monetary equivalent of fishery damage as a percentage of the total value of fish production and length of road damaged as a percentage of the total length of roads in the GP. These data were used to calculate a Flood Hazard Score (FHS) for each GP that gives a quantitative measure of the flood risks associated with each GP. Calculation of the FHS involved the following steps described in detail below.

The paper deals with risk associated with flood. Hence, a flood is defined as an event of inundation having probability to cause loss of assets and lives. As such, severity has been measured in terms of Flood intensity (enumerated by damage volume) and flood magnitude (enumerated in terms of physical aspect). The threshold used to define a flood to be severe has been determined on the basis of flow depth. The data shows that flood depth maintains an approximate linearity with flood damage volume. GP wise flood depth data for a period from 1970-2010 have been obtained from District Collector Office (Natural Calamities Cell), Balasore, 2012.

Flood intensity (measured by FIR) has been assessed in terms of flood damage impacts. As such, the parameters related to damage of assets and lives are considered for which data at the GP level are maintained. GP wise damage data have been obtained from multiple sources like District Collector Office (Natural Calamities Cell), Balasore, 2012, Gram Panchayat Offices of every GP and intensive field survey through pre-designed questionnaire. Because it is hardly possible to collect primary information on damage from each of the GPs. In calculating risk associated with flood should enumerate the real situation of flood impacts as they conceptually incorporate. The effects of protective measures or availability of facilities (like hospitals), if then is any.

Step-I: Computing Critical Value for Designating an Extreme Flood Event

The data set under consideration includes the depth of flood water required during flood events at different points within the studied Block over the last 40 years. Depending on the terrain characteristics, the maximum depth of flood water has always been associated with the recoding station at Rasalpur that represents a low lying area of the Block comprising GPs like Narayanmohantiparia, Shankaari and Kanthibhaunri etc. which are most liable to be inundated even in a low intensity flood event. Therefore, flood depth data recorded at Rasalpur offers opportunity to involve almost all of the flood events in determining threshold to depth severity of flood. Such data allows statistical analysis to determine how often a flood of certain severity (measured in terms of flood water depth as the chosen recording station) is expected. From this analysis a recurrence interval can be determined and or probability for the likelihood of a flood of given inundation depth is calculated thereby. In order to determine the recurrence interval (T), each of the value of flood depth measured at Rasalpur in different flood years is given a rank, m.

With m=1 given to the maximum depth value over the years in record, m = 2 given to the second highest depth and so on. Thus the smallest depth value will receive a rank equal to number of flood years (i.e. 23 years). These ranks are then used to calculate recurrence interval, T by Weibull equation (1951).

$$T = \frac{n+1}{m} \tag{1}$$

where n= number years in records

A graph of flood depth and recurrence interval is plotted to determine 10 years flood depth which is found to be 2.76m (Fig.2). This has been considered as the critical value for designating an extreme flood event. As such, 1977, 2004 and 2008 are the extreme flood years.

Step-II: Computing Flood Magnitude and Flood Intensity Scores

Flood magnitude similar to that of the 2008 flood event was characterized quantitatively using the four parameters mentioned above i.e., depth of flood, flood velocity, percentage of area under inundation and distance from the seashore. The GP-wise data included, data obtained from secondary sources (Table 1) supplemented with data from the field survey. Data for all of the 32 GPs were standardized to make them dimensionless, scale free and comparable. Then, those standardized scores for the

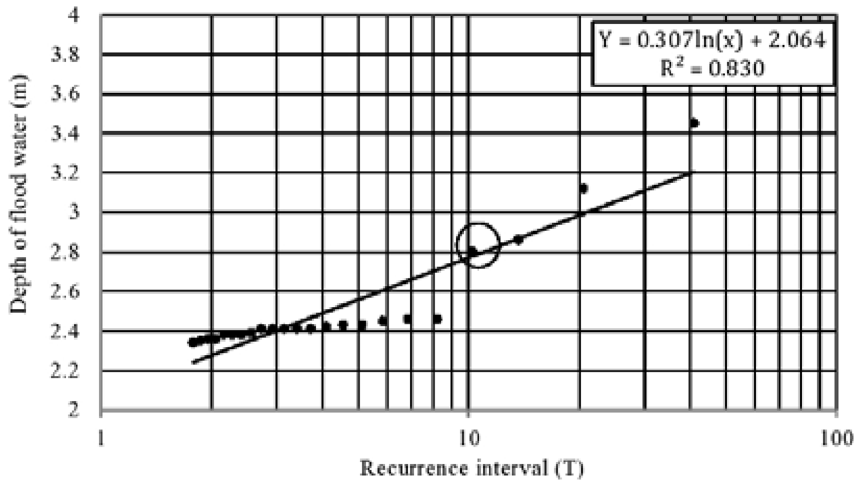

Figure 2. Flood depth and recurrence interval is plotted to determine 10 years flood depth which is found to be 2.76m (encircle within graph). This has been considered as the critical value for designating an extreme flood event.

Table 2. Ranking of Flood Magnitude and Flood Impact in a 10 point scale according to corresponding Standard Score values.

Standardized Value	< -3	-3 to -2	-2 to -1	-1 to 0	0 to 1	1 to 2	2 to 3	>3
Flood Magnitude Rank (FMR) and Flood Impact Rank (FIR)	1	2	3	4	5	6	8	10

aforementioned parameters were averaged to obtain a GP-wise Flood Magnitude Score (FMS) as

$$FM_{GP} = \frac{\sum_{j=1}^{k} z_j}{k} \quad (2)$$

where j= physical parameters of the hazard and k= number of physical parameters for the hazard considered.

The GP-wise damage data can similarly be combined into a Flood Impact Score (FIS) as

$$FI_{GP} = \frac{\sum_{i=1}^{n} z_i}{n} \quad (3)$$

where i=damaged parameters from the hazard, n= number of damaged parameters and z= normalized physical parameters for the considered hazard.

Step-III: Obtaining Flood Severity Scores

For a given flood episode, the GP-wise standardized values of FM_{GP} and FI_{GP} can be ranked on a 10-point scale as shown in Table 2 to obtain the FMR and FIR.

The Flood Severity Score (FSS) for each GP was obtained as the product of the FMR and FIR:

$$FSS = FMR \times FIR \quad (4)$$

Step-IV: Assessing the Probability of Flooding

The probability (P) of the occurrence of a flood of a given magnitude was computed from the recurrence interval (also called the return period). The flood recurrence intervals were determined on the basis of the last 40 years' worth of data. In particular, the recurrence interval (T) was defined as the average number of years between two successive floods of similar severity according to

$$T = \frac{n+1}{m} \quad (5)$$

where n= number of years in the record and m=number of occurrences of floods of a given severity.

The probability (P) of occurrence of floods of a given severity was expressed by taking the inverse of the recurrence interval (T):

$$T = \frac{1}{T} \quad (5)$$

Step-V: Calculating the Flood Hazard Scores

Finally, the FHS was calculated by multiplying the FSS shown in Table 2 with the associated probability value

$$FHS = FSS \times P \quad (7)$$

RESULTS

In this study, we investigated how coastal flood risks vary across the local GPs in the Bhograi block in Odisha, India. All of the 32 GPs in the study area were classified into five categories of flood risk, which ranged from a very low risk category through intermediate classes to a very high risk category (Table 3) and (Table 4). Accordingly a map was prepared on the basis of the calculated FHS for each of the GPs to visualize the spatial variability of risk within the block (Fig 3). The results showed that the Narayanmohantiparia, Rasalpur and Kharidpimpal GPs belonged to the very high flood risk zone, which may be attributed to their vulnerable geomorphic locations. In contrast, the Dehunda, Baunsadiha and Balim GPs were categorized into the very low flood risk class.The other 26 GPs belonged to the other intermediate flood risks classes according to the FHSs that were calculated.

Table 3. Computation of Flood Magnitude Rank (FMR), Flood Impact Rank (FIR), Flood severity Score (FSS), Probability value (P) and Flood Hazard Score (FHS)

GP Code	GP Name	Average Standard Score of Flood Magnitude	Flood Magnitude Rank (FMR)	Average Standard Score of Flood Damage	Flood Impact Rank (FIR)	Flood Severity Score (FSS)	Probability (P)	Flood Hazard Score (FHS)
1	Tukurihazra	0.5937	5	0.7055	5	25	0.1219	3.0475
2	Narayanmohantipadia	1.6204	6	1.3147	6	36	0.1463	5.2668
3	Sharadhapur	0.4727	5	0.1966	5	25	0.1219	3.0475
4	Shankaari	0.2930	5	0.0165	5	25	0.1219	3.0475
5	Huguli	0.4836	5	-0.6715	4	20	0.1463	2.926
6	Bajitpur	0.2222	5	-0.1415	4	20	0.0975	1.95
7	Kakhada	-0.2271	4	-0.0227	4	16	0.0975	1.56
8	Sahuria	-0.8618	4	-0.9763	4	16	0.0975	1.56
9	Nimatpur	-0.2795	4	-0.2285	4	16	0.0975	1.56
10	Barbatia	-0.4219	4	-0.6561	4	16	0.0975	1.56
11	Jayarampur	0.6859	5	0.9570	5	25	0.1219	3.0475
12	Gopinathpur	-0.3640	4	-0.5571	4	16	0.0975	1.56
13	Rasalpur	1.7820	6	-0.7259	4	24	0.1951	4.6824
14	Bhograi	0.5772	5	-0.4500	4	20	0.1219	2.438
15	Sultanpur	-0.5604	4	-0.4128	4	16	0.0975	1.56
16	Guneibasana	-0.7689	4	-0.8286	4	16	0.0975	1.56
17	Dehunda	-1.1190	3	-0.8038	4	12	0.0975	1.17
18	Mandarsahi	-0.7897	4	-0.8484	4	16	0.0975	1.56
19	Deula	-0.7921	4	-0.8618	4	16	0.0975	1.56
20	Analia	-0.8036	4	-0.8218	4	16	0.0975	1.56
21	Mahagab	-0.6437	4	-0.2441	4	16	0.0975	1.56
22	Baunsadiha	-1.0194	3	-0.7494	4	12	0.0975	1.17
23	Putina	-0.6811	4	-0.4481	4	16	0.0975	1.56
24	Kusuda	0.6778	5	-0.6413	4	20	0.1463	2.926
25	Nachinda	0.2139	5	0.6714	5	25	0.1219	3.0475
26	Kharidpimpal	0.6981	5	1.0591	6	30	0.1463	4.389
27	Nahara	-0.0482	4	0.22532	5	20	0.1219	2.438
28	Kashabakamarddha	-0.8213	4	-0.4404	4	16	0.0975	1.56
29	Balim	-1.2574	3	-0.7700	4	12	0.0975	1.17
30	Dehurdha	-0.5762	4	-0.4906	4	16	0.0975	1.56
31	Gunasartha	-1.1125	5	-0.7692	4	20	0.0975	1.95
32	Kanthi Bhaunri	1.4119	6	-0.4299	4	24	0.1219	2.9256

Table 4. Gram Panchayats under different Flood risk classes according to flood hazard scores received.

Sl. No.	Assigned Attribute	G.P. Code	Identified G.P.
< 1.33	Very Low	17, 22, 29	Dehunda, Baunsadiha and Balim
1.33-2.07	Low	6, 7, 8, 9, 10, 12, 15, 16, 18, 19, 20, 21, 23, 28, 30, 31	Bajitpur, Kakhada, Sahuria, Nimatpur, Barbatia, Gopinathpur, Sultanpur, Guneibasana, Mandarsahi, Deula, Analia, Mahagab, Putina, Kashabakamarddha, Dehurdha and Gunasartha.
2.07-3.02	Moderate	5, 14, 24, 27, 32	Huguli, Bhograi, Kusuda, Nahara, Khanthi and Bhaunri.
3.02-4.90	High	1, 3, 4, 11, 25	Tukurihazra, Sharadhapur, Shankaari, Jayarampur and Nachinda.
> 4.90	Very High	2, 13, 26	Narayanmohantipadia, Rasalpur and Kharidpimpal.

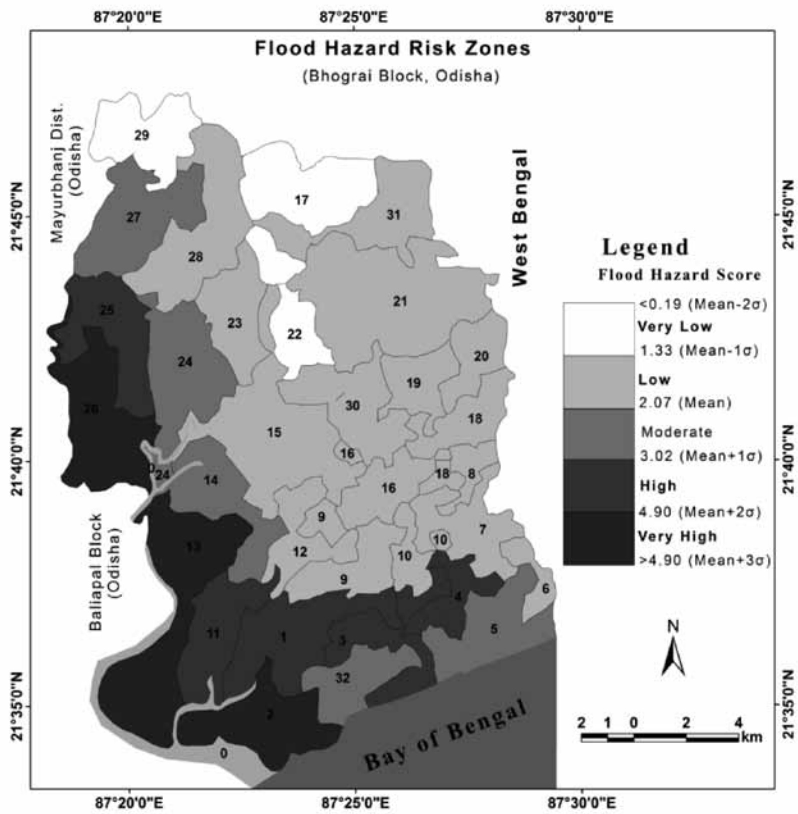

Figure 3. Gram Panchayats (GP) under different flood risk classes according to the calculated flood hazard score (FHS). Classes were taken on both sides around the mean of the FHS values, and the standard deviation was used to define the class width.

It is interesting to note that, despite being located far away from the sea, the Rasalpur and Kharidpimpal GPs had very high risks for flood hazards. The GPs classified under low and very low flood risk zones experienced low intensity and low magnitude flood episodes during river flooding. The duration of flood water inundation was also considerably short in these areas.

The flood impact assessment results have been summarized in graphic form via a plot of the squared values of the average z-scores for the seven hazard impact parameters calculated for each GP in Fig 4.

Out of the seven indices, the fisheries, crop and road damage intensities were very high in the coastal facing GPs and the GPs located along the river bank. Because these regions in the foreshore areas and in the active river flood plain are devoid of settlements, the land is mostly used for agriculture and aquaculture. Settlements near these areas are located on the top of the back barrier dune to

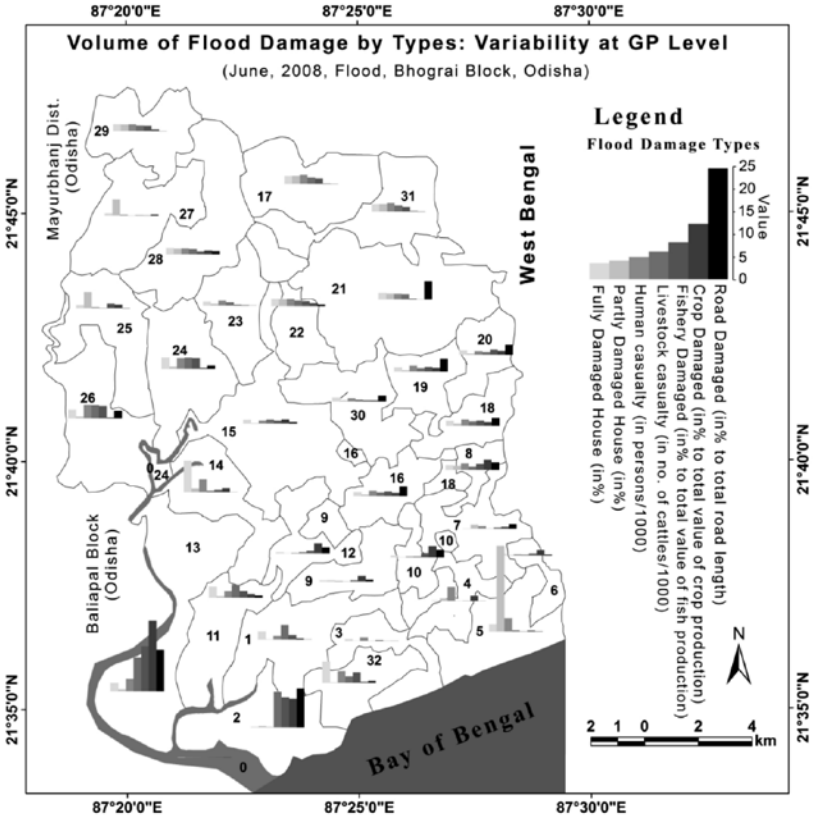

Figure 4. Response of the landscape to flood hazards in terms of damage volume and type, which spatially varies according to terrain characteristics, geomorphological location, protective measures, and flood type and magnitude.

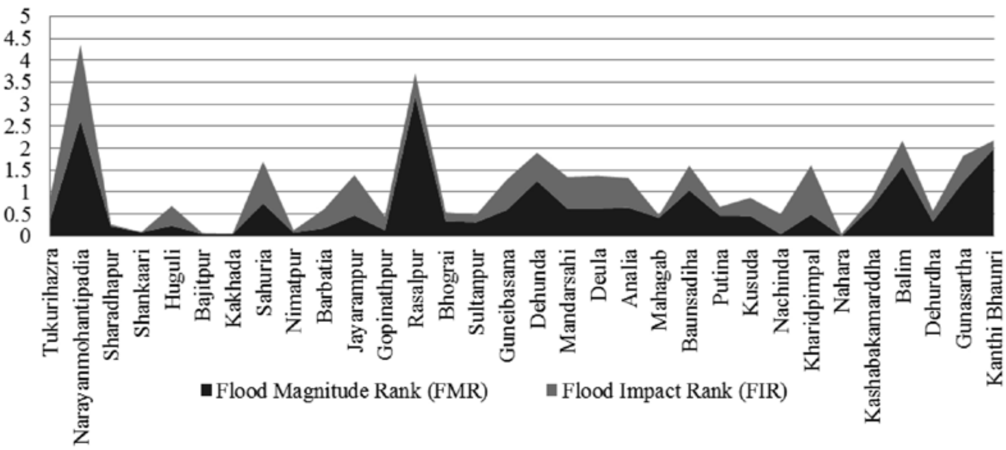

Figure 5. Area graph representing GP-wise comparisons between the Flood Magnitude Rank (FMR) and Flood Impact Rank (FIR). Flood protective measures are capable of reducing flow impacts of even high magnitude floods.

escape the frequent flooding. The coastal GPs with interior settlement locations mostly suffered from crop and road damage, although population impacts were detected because this area is densely populated.

The FMR and FIR received by each of the GPs are shown in an area graph that compares these two aspects of the flood hazard (Fig 5). The data show that in cases like the Huguli, Rasalpur, Bhograi, Kusuda and Kanthi Bhaunri GPs, the impacts from flooding damage were considerably less despite the high magnitude of the flood shown in Fig 5.

DISCUSSION

Geomorphologically, the present study area belongs to the Subarnarekha delta Chenier plain along the eastern bank of the Subarnarekha River. The area is represented by regressive younger beach ridges and mudflats and floodplains appearing as depressed zones are often converted into agricultural fields. The southernmost seafront part of the Bhograi block is composed of beach barrier complex and wash over deposits. Generally speaking, the Bhograi block is dominantly a part of the Subarnarekha flood plain that formed because of the westward avulsion of the river and interactions among marine transgression processes. Huge supplies of sediments and predominant wave-tide dynamics were responsible for the development of this sandy flat area, which is surrounded by the Subarnarekha river in the west, the young Chenier complex to the east & north and the beach barrier complex and wash over deposits to the south. The geomorphological signatures 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 rain in the upper catchment of the Subarnarekha river have been found to be responsible for flooding in the study area and the intensity and severity of the flooding have increased possibly due to recent climate and environmental changes.

Narayanmohantiparia is located at the seafront; hence, it is prone to coastal flooding. Moreover, the Subarnarekha river carries large volumes of discharge loaded with enormous quantities of sediment. This discharge flow receives resistance to its drainage from a number of factors including the strong southwesterly monsoon wind and resultant cross-shore current, waves and high magnitude tidal inflows. These conditions cause the accumulation of large amounts of water at and near the mouth of the Subarnarekha river, which causes flooding at Narayanmohantiparia. Moreover, this area is only 0.5m -1m above from sea level, which makes the area more vulnerable to flooding. The landward margin of the block under study is characterized by an intricate network of tidal inlets along which sea water can enter into the nearby GPs and cause flooding, even in the event of low storm surges or waves of moderate magnitude. The above stated GP is barely exposed to the sea without any sand dunes that generally act as a natural buffer against the sea. A mud embankment was once built to protect the GP from flood hazards, but it has been completely washed away by episodic strong sea waves and only remnants of its basement can be found in a few places on the beach. Sparse mangrove patches, which were present in this area a few years ago, have disappeared because of changes in sedimentological properties of the shore deposits that constitute substrates for mangrove swamps. Landuse patterns in the area have also undergone recent changes that have increased the probability for flooding.

The Narayanmohantiparia GP becomes flooded in two different ways. The first is due to the spilling of the Subarnarekha River (sweet water flood) and the second is caused by coastal flooding (saline flood) from high magnitude waves or storm surges. This GP is densely populated mainly because people here have easy access to marine resources, which the coastal dwellers utilize for their livelihoods. Therefore, flood damage in this GP is typically very high even in the event of moderate intensity floods.

Rasalpur and Kharidpimpal, the other two GPs that were found to have very high flood risks, are located along the eastern bank of the Subarnarekha river where the river follows a meandering course. Because of the high degree of sinuosity in the estuarine section of the Subarnarekha, the gradient flow 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 astronomical 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 flooding 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 Rasalpur. Hence, the funneling effect of tidal water as it enters into the estuary is a major cause of flooding in Rasalpur. 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 Bhograi block 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. At these 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 river has also changed the hydrological conditions in this region. These river embankments restrict sedimentation within the area between the banks and leave no scope 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.

For GPs like Huguli, Rasalpur, Bhograi, Kusuda and Kanthi Bhaunri, the damage from flooding was low even though these areas experienced a high magnitude flood. The damage from flooding was likely low in these GPs because of protective measures that were taken to mitigate the impacts of floods. For example, a sea wall was constructed in the Huguli GP for shore line protection. Additionally a number of cyclone and flood shelters have been installed near Chandaneswar, which have immensely helped in reducing losses due to floods. Awareness programs and training camps are being organized to increase the capacity of local communities to cope with flooding situations. In Rasalpur and Bhograi, river embankments have been heightened under the National Rural Employment Guarantee Act program. Above all, floods and cyclones can now be predicted precisely with the use of modern technology and preparedness levels which have been strengthened to the highest level ever. All of these activities have contributed to a reduction in the impacts of high-intensity floods in many of the GPs within the Bhograi block.

CONCLUSIONS

The Bhograi block in Odisha, India, consists of 32 GPs that are located on the coastline and the banks of the Subarnarekha river. This area is geomorphologically vulnerable to coastal hazards and prone to frequent flooding. Spatial variability of flood risks among the GPs was assessed quantitatively by considering both the magnitude of floods that the GP are likely to experience and the impacts of those floods measured from damage caused by previous flood events. A combination of these two characteristics of the flood hazard along with the probability of occurrence yielded a FHS for each of the 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 a high risk for flooding impacts, whereas GPs in interior locations are generally in zones of lower risk. The gradual decline in the capacity of the Subarnarekha river to hold large volumes of water received from high-magnitude storm events has augmented this vulnerability to flooding. The situation has become critical during monsoons when the inflow of tidal water along the river channel raises water levels. Storm surges during cyclonic episodes and high astronomical tides also lead to the buildup of ocean water that can enter the area along tidal inlets. The last two processes were responsible for exacerbating previous floods in many of the GPs under study. Moreover, embankments used in aquaculture around fish ponds may be responsible for intensifying the severity of the floods. Variation was also observed among the GPs with respect to the types of damage caused by floods. The results from this study show that protective measures against floods have been effective in reducing the damage of even high magnitude flood events.

Overall, the essence of this work lies in the fact that it explores the causes and consequences of flooding in a quantitative manner via the use of flood hazard scores and this was done at a reasonably low scale of geography where it may be feasible to implement risk reduction programs. Specifically, the results from this study may help environmental managers to better understand coastal flooding risks in different local GPs in the Bhograi block in Odisha, India. Notably, the damage experienced by the GPs during flooding in terms of lives and properties lost was not always linearly dependent on the physical severity of the flood. 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 flood management. Moreover, this type of study can be carried out for other coastal blocks, which would allow for the creation of more comprehensive coastal hazard maps and a better assessment of the risks associated with coastal hazards.

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