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Physical Sensitivity and Social Exposure of Flood Hazard Risks in Subarnarekha Delta Plain, Odisha, India

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ABSTRACT

The Present study is recompenses on determining and estimating the coastal flood hazard risk through quantification of flood intensity and crashes across the different Gram Panchayats (GPs) of Bhograi, Baliapal and Balasore coastal block in Subarnarekha delta plain, Odisha, India. With reverence to the June, 2008 flood episode, extent of flooding has been calculated for each GP using normalised values of measurable factors relating flood characteristics. Thus, a Flood Magnitude Rank (FMR) has been consigned to each of the GPs according to extent of flooding brutality. Similarly, Flood Impact Rank (FIR) for each GP has been derived from damage database. The product of FMR and FIR gives Flood Severity Score (FSS) of a particular GP which multiplied by probability of flood event occurrence and yields Flood Hazard Score (FHS) for the concern GP. The analysis helps dividing the study area into five flood risk zones viz. (a) Very Low (FHS Below 12.07); (b) Low (FHS 12.07 - 37.31); (c) Moderate (FHS 37.31 - 60.00); (d) High (FHS 60.00 - 80.78) and e) Very high (FHS Above 80.78), respectively. Narayanmohantipadia, Kanthi Bhaunri of Bhograi block, Jambhirai, Madhupura, Panchupali, Dagra, Choumukha of Baliapal block and Padmapuri, Ranasahi, Sindhia, Srirampur, Hidigaon, Srikona, Balasore Town of Balasore block falls in very high flood hazard risk class while, Sahuria, Guneibasana, Dehunda, Mandarsahi, Deula, Analia, Mahagab, Baunsadiha, Nachinda, Kashabakamarddha, Balim, Gunasartha of Bhograi block and Mahakumaremu, Kumbhari, Nikhira of Baliapal block tend to have very low risk from flood hazards. The rest 57 GPs of area under study come under different risk classes in between the above two acute classes according to their flood hazard scores.

1. Introduction

The present studied coast are exposed to variety of coastal hazards as these are the zones of interface between aquatic and terrestrial systems and perilous processes that initiate from both land and sea of coastal stretch. Assortment makes them very susceptible to those processes and responses are highly intricate also. In the perspective of growing significance of the coastal zones because of high

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efficiency of the ecosystem, increasing absorption of population, industrial development, more intensive resource exploitation, intensifying recreational activities etc. – apprehension about coastal hazards has amplified and there is a require for effective coastal management to reduce these impacts of disaster events. The Swaminathan committee has recommended vulnerability as an imperative deliberation in coastal zone management. Assessment of the physical sensitivity and exposure of coasts to hazards is an indispensable constituent for any comprehensive coastal vulnerability study. During the last few decades, a plethora of literatures on coastal risk assessment methods have been produced resulting upon the respect of global climate change and resultant sea level rise to put the coastal habitats and coastal communities into real threats.

A seven steps common methodology developed by IPCC's coastal zone management sub group (CZMS) was employed to assess the coastal vulnerability of various coastal nations to predict the sea level rise (IPCC–CZMS, 1992). This method also considered the probable impacts of global sea level rise on population, economic sector, ethnicity, and social assets and on agricultural productions. But the data for single or many stricture considered in it were either insufficient or not easily available (Kelvin and Nicholls, 1999). Kay and Waterman (1993) developed a four step methodology to overcome this limitation associated with CM. The four stages were physical and biological environment study of the area under consideration; vulnerable and cultural system; links between different parts of the area and finally, formulation of management strategy. Harvey *et al*. (1999) was criticized this method, on the ground that physical, biological environment of the study area was feebly defined and man induced coastal hazards were not accurately considered. Hervey and his colleagues developed an eight-step methodology in which the above discrepancies were removed. Most important contribution in this regard came from Gronitz *et al*. (1994) that considered parameters like relief, rock type, landform, tectonics and shoreline shift for calculating Coastal Vulnerability Index (CVI). This method has been exercised by United States Geological Survey (USGS) for mapping the vulnerability of coastal stretches throughout USA. But without any consideration of socio-economic data has been logically criticized (Shaw *et al*., 1998; Aboudha and Woodroffe, 2010 Kumar *et al*., 2010). Any assessment of coastal vulnerability without reference to social aspect is not useful (Klein and Nicholls, 1999). Accordingly, the social vulnerability index (Cutter *et al.* 2003) and CVI were combined to develop 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 Place Vulnerability Index (PVI) (Cutter, 1996). The main cause of coastal flooding in the coastal parts of the state of Odisha, India, flood hazards are generally tropical cyclones and very rarely by tsunamis. The extent of flooding depends upon scale of the storm, height of storm surge and the tide level at the time of the event. Global sea level rise will be an increasingly important factor if predicted rise in sea level do occur. River estuaries may witness severe estuarine flooding with combined effects of a storm surge and river flood caused by rain storm inland. Coastal flooding is the most severe hazard in many coastal locations around the Bay of Bengal.

2. Study area

The present study area, Balasore coastal stretch, Odisha, India has of 3 coastal blocks with 86 Gram Panchayats along with a municipal area. This is located at the alluviums coast of Subarnarekha delta plain. It extends from Udaipur to Rasalpur-I Gram Panchayat along the Bay of Bengal coast of Odisha. The study area lies between 21°20'25"N to 21°39'55"N and 87°8'45"E to 87°38'35"E (Fig. 1).

Subarnarekha delta plain is a coastal alluvial expanse with an unconsolidated substrate, which is also geomorphologically dynamic, wealthy in habitat multiplicity and locationally lying face down to hazard like tropical cyclone induced tidal waves, storm surges and resultant coastal flooding. It is a uneventfully unexciting alluvium surface lying between 2.5 m. to 3.5 m. above MSL. Geologically the area is pigeonholed by ordinary alluvium deposits of the Holocene to recent origin brought down by the Dugdugi, Burahbalam and also Subarnarekha river. The area has a natural gradient to the east and south east direction which has been followed by the river Subarnarekha. The study area is predominantly roofed by the sandy clay and silty loam soils developed under brackish environment. The pH of the soil varies between 6.5 and 8.0 (pre monsoon) and 6.2 and 8.2 (post monsoon). This type of soil has led to a high water preserving capacity of the area. The significant climatic variations of the study area are between monsoon and pre monsoon seasons. Temperature fluctuates from a minimum of 9°C in winter to a

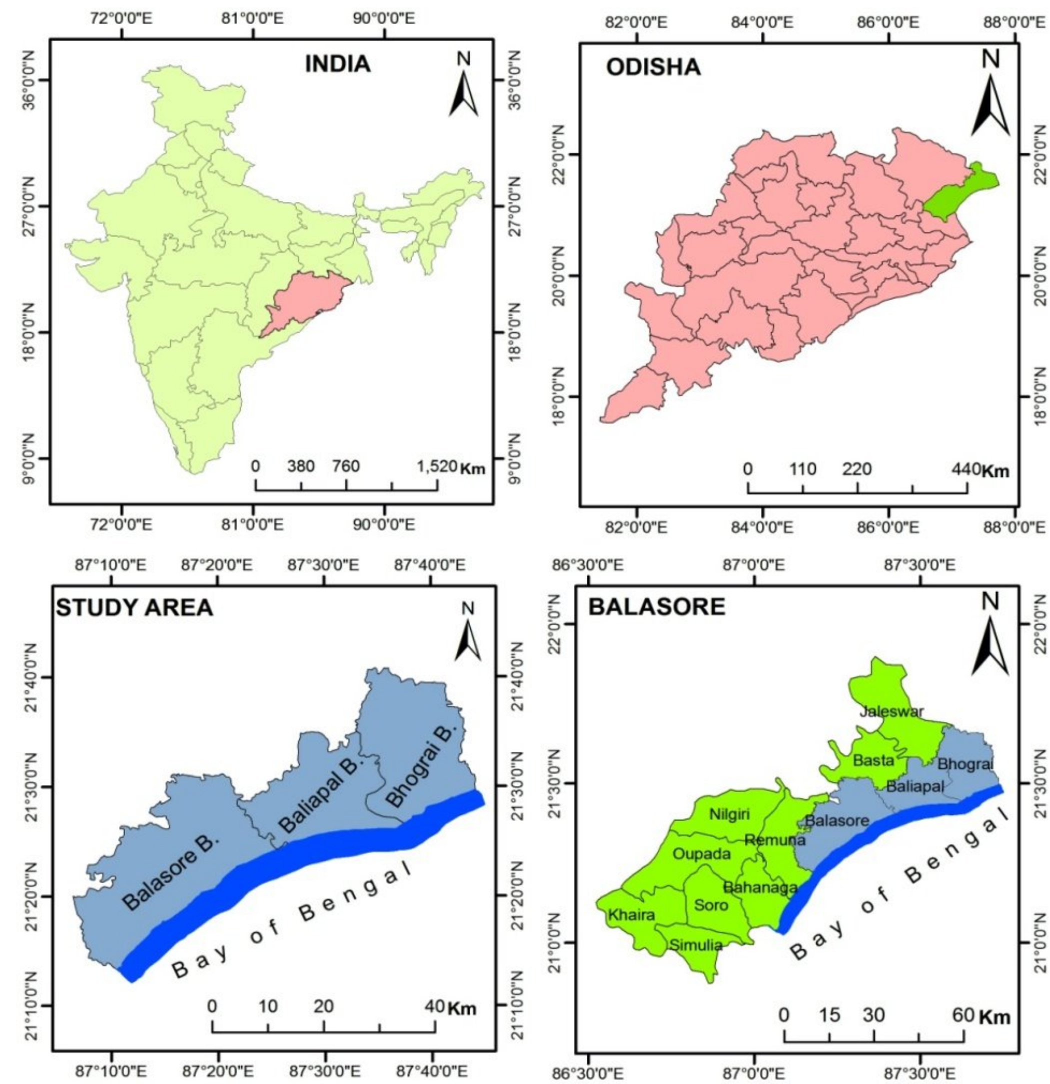

Fig. 1 Location of the study area

maximum of 38°C in summer. Relative humidity assortment is in between 90% – 96% in most of the months. Low atmospheric pressure is frequently occurred during summer and monsoon period. Wind dominantly blows from the offshore areas. There is no forest land in the study area. Some grasses e.g. *Sesuvium Portolacrustum*, *Ipomia Bioloba* and some herbs like *Lantena camera, Akanthesia*, *Calatropis gigantia* are found in the study area. Trees like *Casuarina, Eucalyptus* and *Acacia auriculiformis* are planted in this area while Coconut, Banana, Bamboo and Mango are indigenous floral species.

3. Data Base and method

The present study has been completed with the help of Gram Panchayat (GP) wise secondary data collected from Gram Panchayat office, Block Development Office, District Natural Hazard Management Office of Balasore district, Odisha and primary data collected aftermath of June, 2008 flood event through rigorous field survey with predesigned questionnaire at randomly sampled households to represent the flood magnitude and severity of concerned GP. The study has been conducted considering Gram Panchayat (GP) as the smallest administrative unit for which disaster damage database is maintained and also the variations of flooding characteristics is considered. Moreover, the socio-economic and demographic features of the population exhibit an acceptable degree of homogeneity at the Gram Panchayat level. To estimate the Flood Magnitude Rank (FMR) of a GP four parameters have been considered these are depth of flood; flood velocity; percentage of area under inundation and distance from sea shore. On the other hand, seven indicators have also been chosen to enumerate Flood Impact Rank (FIR) for each GP. The seven chosen parameters are percentage of fully damaged houses; percentage of partly damaged houses; number of people died per thousand; number of cattle died per thousand of cattle population; monetary equivalent of crop damage per hector of net cropped area; monetary equivalent of fishery damage as a percentage of total value of fish production; length of road damaged as a percentage of the total length of roads in the these GPs respectively. By use of these data, Flood Hazard Score for each GP has been calculated which gives a quantitative measure of flood risk associated with a GP. Calculation of Flood Hazard Score (FHS) involves following steps

Step-I: Obtaining the normalised value of flood events database

The data on magnitude and different damage impacts of said flood event are to be normalised by using Gaussian Distribution Process for making them standardized and dimension less. One of the best known probability density functions is that forming the familiar bell shaped curve for the normal distribution:

$$f = (x) = \frac{1}{\sqrt{2\pi\sigma}} e\left(-\frac{(x-\mu)^2}{2\sigma^2}\right) \qquad (1)$$

where, μ and σ are physical parameters of hazards. This function can be simplified by defining the standard normal variable z as:

$$z = \frac{x-\mu}{\sigma} \qquad (2)$$

The corresponding standard normal distribution has probability has density function

$$f(z) = \frac{1}{\sqrt{2\pi}} e^{-z^2/2} \qquad -\infty \le z \le \infty \qquad (3)$$

This depends only on the value of z. The standard normal probability distribution function

$$F(Z) = \int_{-\infty}^{Z} \frac{1}{\sqrt{2\pi}} e^{-\mu^2/2\partial\mu} \qquad (4)$$

Where u is a dummy variable of integration has no analytical form to the considered hazards.

These values may be approximated by the following polynomial (Abramowitz and Stegun, 1965):

$$B = \frac{1}{2}[1 + 0.196854|z| + 0.115194|z|^2 + 0.000344|z|^3 + 0.019527|z|^4]^{-4}$$

where |z| is the absolute value of z, hazards parameters and the standard normal distribution has

$$F(z) = B \quad \text{for } z < 0$$
$$= 1 - B \text{ for } z \ge 0 \qquad (5)$$

The error in F (z) as evaluated by this formula is less than 0.00025.

Step-II: Computing flood magnitude and flood intensity score

The dimensionless flood magnitude data of four parameters namely flood velocity, percentage of area under inundation and distance from sea shore of all the 86 GPs along with Balasore municipal area analogous to that of 2008 flood event has been characterized quantitatively and averaged to get GP wise Flood Magnitude Score (FMS)

$$FM_{GP} = \frac{\sum_{j=1}^{k} z_j}{k} \qquad (6)$$

where, j, physical parameters of hazard; k, number of physical parameters of hazard to be taken; z, normalized physical parameter for the hazard considered.

GP wise damage data can similarly be combined into a Flood Intensity Score as follows

$$FI_{GP} = \frac{\sum_{i=1}^{n} z_i}{n} \qquad (7)$$

where, *i*, damaged parameters of hazard; *n*, number of damaged parameters of hazard to be taken.

Step-III: Obtaining Flood Severity Score

For the given flood episode, GPs wise standardised values of FM_{GP} and FI_{GP} can be ranked on a 10 point scale (Table 1) to get the Flood Magnitude Rank and also the Flood Impact Rank (FIR)

Flood Severity Score of each and every GP has been quantified by the product of FMR and FIR.

$$FSS = FMR \times FIR \qquad (8)$$

Table 1. Ranking of Flood Magnitude and Flood Impact from Standard Scores

Standardised 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

Step-IV: Assessing Probability of flooding

Probability (p) of the occurrence of said flood of a given magnitude is computed from recurrence interval (also called the return period). Flood recurrence interval has been computed on the basis of last 40 years worth of data. The recurrence interval (T) is defined as the average number of years between two successive floods or similar severity. Recurrence Interval (T) is given by

$$T = \frac{n+1}{m} \tag{9}$$

where, n, number of years in record; m, number of occurrences of flood of similar severity

The probability (p) of occurrence of said floods of a given severity is expresses by taking the inverse of recurrence interval (T)

$$P = \frac{1}{T} \tag{10}$$

Step-IV: Calculating Flood Hazard Score

Finally, the Flood Hazard Score (FHS) is calculated by multiplying the Flood Severity Score (FSS) (Table 2) and the associated probability value

$$FHS = FSS \times p \tag{11}$$

4. Results and discussion

From the geomorphological point of view, the present study area lies on the Subarnarekha delta Chenier plain with active zone of fluvial, marine and terrestrial processes and frequent tropical cyclones and allied natural disturbances. Which are very complex, diverse and fragile in nature. Coastal ecological unit, such as wetlands, beaches, lagoon, estuaries, sand dunes, and mangroves, is always performing several parallel systems such as, provide rich swamping and breeding grounds for marine creatures, feeding grounds for birds, recreational grounds for tourists and available resources for the local communities. These ecosystems are endangered by development related activities along the Balasore coast. The area is represented by regressive younger beach ridges and mudflats and floodplains appearing as depressed zones, after altered into agricultural field. The southernmost sea front part of Balasore coastal stretch is composed of beach barrier complex and wash over deposits. Generally speaking, the Balasore coastal stretch is dominantly the part of Subarnarekha, Burahbalam and Dugdugi flood plain formed due to westward avulsion of these three main river. Interactions among maritime transgression processes, huge supply of sediments and predominant wave tide dynamics have been conscientious for the development of this sandy flat area surrounded by the Bhadrak district in the west, young chenier complex to the east and north and beach barrier complex and wash over deposits to the south.

Geomorphological signatures suggest that this coastal area has probably started to witness a phase of marine transgression. Frequency and intensity of the cyclones have increased to a certain extent. Cyclone induced storm surges and torrential rain in upper catchment of Burahbalam and Dugdugi river have been found to be responsible for flooding of the study area intensity and severity of which are experienced to have increased, may be due to recent climate and environment changes. From this study it has been tried to understand, the degree of flood hazard risk across the Gram Panchayats in Subarnarekha delta, Odisha. All the Gram Panchayats (86 in number along with Balasore municipal area) of the studied coastal stretch have been classed under five categories of flood hazard risk - starting from Very Low through intermediate classes to Very High (Table 3) and accordingly a map (Fig. 2) has been prepared on the basis of calculated flood hazard score of each of the GPs to imagine spatial changeability of risk within the GPs under study. Result shows that Narayanmohantipadia, Kanthi Bhaunri of Bhograi block, Jambhirai, Madhupura, Panchupali, Dagra, Choumukha of Baliapal block and Padmapuri, Ranasahi, Sindhia, Srirampur, Hidigaon, Srikona and Balasore Town of Balasore block belong to very high flood risk zone which may be attributed to their vulnerable geomorphic locations. Narayanmohantipadia, Kanthi Bhaunri of Bhograi block, Jambhirai, Panchupali, Dagra, Choumukha of Baliapal block and Padmapuri, Ranasahi, Hidigaon, Srikona, of Balasore block is located at the sea front and hence, prone to coastal flooding. Moreover, river Subarnarekha, Burahbalam and Dugdugi carries large volume of discharge loaded with huge quantity of

Table 2: Result of Average Standard Score, Flood Magnitude Rank (FMR), Flood Impact Rank (FIR), Flood severity Score (FSS), Probability value (p) and Flood Hazard Score (FHS)

Block	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)
Bhograi	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	0.293	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	0.957	5	25	0.1219	3.0475
	12	Gopinathpur	-0.364	4	-0.5571	4	16	0.0975	1.56
	13	Rasalpur	1.782	6	-0.7259	4	24	0.1951	4.6824
	14	Bhograi	0.5772	5	-0.45	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	-1.119	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	-0.77	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 2 contd....

sediments. This flow of discharge instigates confrontation in its natural flow from the strong south-westerly monsoon wind and resultant cross-shore current, waves and high magnitude tide inflow. This causes accumulation of huge water at and near Burahbalam and Dugdugi river mouth and flooding the upper portion of these said rivers at Madhupura of Baliapal block and Sindhia, Srirampur and Balasore Town of Balasore block. On the other hand this area is only 0.5m - 1m high above the sea level which makes the area more vulnerable to flooding. The landward margin of the block under study is characterised by complex network of tidal inlets along which sea waters can enter into the said GP in question and cause flooding even in the event of a low storm surge or a wave of moderate magnitude. The above stated GPs of seafront situation are highly exposed to sea without any sand dune which generally acts as a natural buffer against sea. Thin mangrove scrap, which could be found in this area even few years back, have disappeared due to change in sedimentological belongings of the shore deposits that constitute substrate for mangrove swamps. Land use pattern of present study area has undergone such changes that have amplified probability of flooding.

The area gets flooded in two different ways – firstly

Block	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)
Baliapal	1	Bolonga	1.0629	6	-1.2573	3	18	0.1463	2.6341
	2	Kunduli	0.5097	5	-1.2121	3	15	0.1219	1.8292
	3	Baniadiha	-0.2216	4	-0.0139	4	16	0.0975	1.5609
	4	Nuagaon	0.4937	5	-1.0456	3	15	0.1219	1.8292
	5	Ratei	-0.42	4	-0.3757	4	16	0.0975	1.5609
	6	Jambhirai	0.9945	5	-1.1162	3	15	0.1219	1.8292
	7	Jagajipur	-0.2701	4	-0.1197	4	16	0.0975	1.5609
	8	Badas	0.4529	5	-1.2729	3	15	0.1219	1.8292
	9	Pratappur	-0.333	4	-0.1994	4	16	0.0975	1.5609
	10	Madhupura	-0.7974	4	-0.5404	4	16	0.0975	1.5609
	11	Balikuti	-0.7183	4	-0.3028	4	16	0.0975	1.5609
	12	Deula	-0.6285	4	-0.0599	4	16	0.0975	1.5609
	13	Jamkunda	0.6859	5	1.2546	6	30	0.1219	3.6585
	14	Srirampur Mahakumaremu	-1.4058	3	-1.4267	3	9	0.0731	0.6585
	15	Kumbhari	-1.3971	3	-1.3658	3	9	0.0731	0.6585
	16	Nikhira	-1.1876	3	-1.1618	3	9	0.0731	0.6585
	17	Baliapal	-0.3824	4	-0.296	4	16	0.0975	1.5609
	18	Bishnupur-mahakumanayabali	0.4162	5	0.3402	5	25	0.1219	3.0487
	19	Asti	-0.2504	4	-0.0428	4	16	0.0975	1.5609
	20	Debhoga	-1.1972	3	-1.1932	3	9	0.0731	0.6585
	21	Ghantuai	-0.9936	4	-1.1152	3	12	0.0975	1.1707
	22	Panchupali	0.2301	5	-0.0677	4	20	0.1219	2.439
	23	Betagadia	0.4586	5	0.2927	5	25	0.1219	3.0487
	24	Anladiha	0.581	5	0.4443	5	25	0.1219	3.0487
	25	Dagra	0.8791	5	0.8217	5	25	0.1219	3.0487
	26	Choumukha	1.4847	6	1.6147	6	36	0.1463	5.2682
	27	Balarampur	-0.7944	4	-0.4818	4	16	0.0975	1.5609
Balasore	1	Rasalpur I	0.702	5	-1.0873	3	15	0.0731	1.0975
	2	Sashanga	0.0682	5	-0.3747	4	20	0.0975	1.9512
	3	Joydebkasba	0.6912	5	1.0237	6	30	0.1463	4.3902
	4	Saragaon	-0.6743	4	-0.7547	4	16	0.0975	1.5609
	5	Genguti	-0.504	4	-0.43	4	16	0.0975	1.5609
	6	Gudu	0.3194 2	5	-0.0177	4	20	0.0975	1.9512
	7	Padmapuri	0.0801	5	-0.4636	4	20	0.0975	1.9512
	8	Ranasahi	0.413	5	-0.0001	4	20	0.0975	1.9512
	9	Patrapada	-1.0838	3	-1.1517	3	9	0.0731	0.6585
	10	Parikhi	0.9398	5	1.5748	6	30	0.1463	4.3902
	11	Bahabalpur	0.7948	5	1.2433	6	30	0.1463	4.3902
	12	Gopinathpur	-0.2723	4	-0.1051	4	16	0.0975	1.5609
	13	Chhanua	-0.3384	4	-0.1864	4	16	0.0975	1.5609
	14	Sindhia	-0.6615	4	-0.2311	4	16	0.0975	1.5609
	15	Olanda Saragaon	-0.5988	4	-0.095	4	16	0.0975	1.5609
	16	Odangi	-0.7014	4	-0.8936	4	16	0.0975	1.5609
	17	Nagram	-0.7476	4	-0.8755	4	16	0.0975	1.5609
	18	Baunla	-0.7351	4	-0.8235	4	16	0.0975	1.5609
	19	Haldipada	-1.0563	4	-0.9395	4	16	0.0975	1.5609
	20	Kasipada	-0.9827	4	-0.8488	4	16	0.0975	1.5609
	21	Sartha	1.2745	3	2.1505	8	24	0.1951	4.6829
	22	Kashaphala	0.8717	5	-1.1869	3	15	0.0731	1.0975
	23	Srirampur	0.6848	5	0.589	5	25	0.1219	3.0487
	24	Rasalpur II	-0.7077	4	-1.1483	3	12	0.0731	0.878
	25	Hidigaon	0.6405	5	-1.2481	3	15	0.0731	1.0975
	26	Srikona	0.9681	5	1.5495	6	30	0.1463	4.3902
	27	Kuradiha	-0.642	4	-0.7254	4	16	0.0975	1.5609
	28	Balasore Town	-1.4024	3	-1.0805	4	12	0.0975	1.1707

due to spilling of river Subarnarekha, Burahbalam and Dugdugi (Sweet water flood) and coastal flooding (Saline flood) due to high magnitude wave or storm surge. These GPs are thickly populated because people here have easy access to marine resources which these coastal dwellers utilize for earning livelihood. Narayanmohantipadia, Kanthi Bhaunri of Bhograi block, Jambhirai, Panchupali, Dagra, Choumukha of Baliapal block and Padmapuri, Ranasahi, Hidigaon, Srikona, of Balasore block have a very high damage volume even in the event of a moderate intensity flood. Sindiha and Balasore municipal area of Balasore block located along the eastern and western bank of river Burahbalam respectively. Srirampur GP of Balasore block located along the eastern bank of river Dugdugi and madhupura GP of Baliapal block situated at the right bank of river Subarnarekha where all these three main river follows a meandering course. Due to high degree of sinuosity in the estuarine section of Subarnarekha, Dugdugi and Burahbalam rivers, the gradient flow of river discharge gets largely obstructed particularly during monsoon. Torrential rainfall in the gigantic catchment of these three rivers contributes a huge volume of discharge that fails to get drained seamlessly. As such, these rivers often spill in rainy season to cause reverine flood in those afore said GPs and municipal area. Moreover, during high astronomical tide phase, considerable huge volume of ocean water ingresses through this funnel shaped estuary of mentioned three rivers in the form of tidal bore which restricts river discharge to be drained into sea. As a consequence, water level in river valley becomes high enough to spill over its banks causing flood. Funnelling effect of tidal water as it enters into the estuary is a major cause of flooding in those GPs which are situated at the riverine flood plain.

In spite of being located far away from the sea, afore said GPs and the municipal area have very high of flood hazard only due to its riverine flood plain location. The GPs under low and very low flood hazard risk zone experience low intensity and low magnitude flood episodes spilling of river. Duration of flood water stay in those areas is also considerably short. Alteration of land use pattern of this coastal low lying area has also been answerable for recurrent flooding. Aquaculture has materialized as a profitable economic

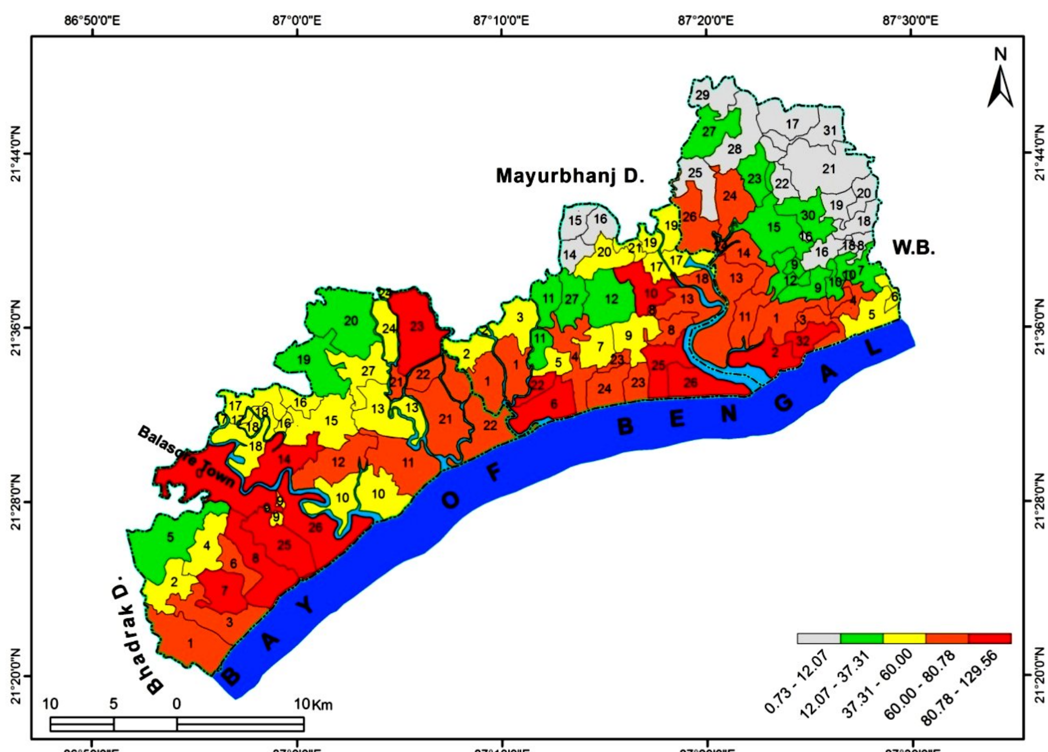

Fig. 2 Flood Hazard Risks Zone

Table 3. Gram Panchayat wise distribution of Flood Hazard Score with their assigned attribute

Flood Hazard Score	Assigned Attribute	Block	G.P. Code	Identified G.P.
0.73 - 12.07	Very Low	Bhograi	8, 16, 17, 18, 19, 20, 21, 22, 25, 28, 29, 31	Sahuria, Guneibasana, Dehunda, Mandarsahi, Deula, Analia, Mahagab, Baunsadiha, Nachinda, Kashabakamarddha, Balim, Gunasartha.
		Baliapal	14, 15, 16	Mahakumaremu, Kumbhari, Nikhira.
		Balasore	NA	NA
12.07 - 37.31	Low	Bhograi	7, 9, 10, 12, 15, 23, 27, 30	Kakhada, Nimatpur, Barbatia, Gopinathpur, Sultanpur, Putina, Nahara, Dehurdha.
		Baliapal	11, 12, 27	Balikuti, Deula, Balarampur.
		Balasore	5, 19, 20	Genguti, Haldipada, Kasipada.
37.31 - 60.00	Moderate	Bhograi	5, 6	Huguli, Bajitpur.
		Baliapal	2, 3, 5, 7, 9, 17, 19, 20, 21	Kunduli, Baniadiha, Ratei, Jagajipur, Pratappur, Baliapal, Asti, Debhoga, Ghantuai.
		Balasore	2, 4, 9, 10, 13, 15, 16, 17, 18, 24, 27	Sashanga, Saragaon, Patrapada, Parikhi, Chhanua, Olanda Saragaon, Odangi, Nagram, Baunla, Rasalpur II, Kuradiha.
60.00 - 80.78	High	Bhograi	1, 3, 4, 11, 13, 14, 24, 26	Tukurihazra, Sharadhapur, Shankaari, Jayarampur, Rasalpur, Bhograi, Kusuda, Kharidpimpal.
		Baliapal	1, 4, 8, 13, 18, 23, 24	Bolonga, Nuagaon, Badas, Jamkunda, Bishnupur- mahakumanayabali, Betagadia, Anladiha.
		Balasore	1, 3, 6, 11, 12, 21, 22	Rasalpur I, Joydebkasba, Gudu, Bahabalpur, Gopinathpur, Sartha, Kashaphala.
80.78 - 129.56	Very High	Bhograi	2, 32	Narayanmohantipadia, Kanthi Bhaunri.
		Baliapal	6, 10, 22, 25, 26	Jambhirai, Madhupura, Panchupali, Dagra, Choumukha.
		Balasore	7, 8, 14, 23, 25, 26, Balasore Town	Padmapuri, Ranasahi, Sindhia, Srirampur, Hidigaon, Srikona, Balasore Town.

activity at present. Hence, vast extension of land have been given to fish farming ponds where high earthen embankments have been assembled around the ponds which restrict the flow water to spread over flood plain and causing the flood situation to become more severe. River engineering in the form of embankment construction along the both banks of river Subarnarekha, Burahbalam and Dugdugi have caused sedimentation to be restricted between the banks along leaving no scope for sediment distribution over the floodplain. This has reduced the capacity of the river valley and increased a huge enumerates of sediment to deposit near their mouth, which causing gradual narrowing of the channel thereby. The flood impact assessment results have been abridged in a graph plot of averaged standard values of seven considered hazard impact parameters calculated for every GP [Fig. 3(*a*), 3(*b*), 3(*c*)]. Out of the seven indices fisheries, crop and road damages intensity is very high at the coast facing GPs along with the GPs located along the river bank because there are no such settlement sites are present in the active river flood plain and also the foreshore region. These pointed out regions have mainly been used for primary activities like agriculture and fisheries. All the settlements have been developed on the top of the back barrier dune to shield the frequent natural disaster.

On the other hand, the coastal GPs having interior locations are mostly suffers from crop and road damage and in terms of number of population affected because this area is densely populated.

Flood Magnitude Rank (FMR) and Flood Intensity Rank (FIR) received by each of the GPs have been represented by radar chart which compares between the two aspects of flood hazard for the GPs. It shows that flood intensity or damage impacts of GPs like Rasalpur, Kanthibhaunri of Bhograi block, Bolonga, Kundali, Nuagaon, Jambhirai and Badas of Baliapal block and Panchupali, Rasalpur-I, Gudu, Padmapuri, Ranasahi, Kashaphala, Rasalpur-2 and Hidigaon of Balasore block is much less in spite of high magnitude of flood. It may be explained in terms of the protective measures undertaken for alleviation of flood impacts in those GPs. For example, in Hidigaon GP sea wall has been constructed for shore line protection. Besides, number of cyclone and flood shelters has been installed near Ranasahi and Kashaphala which immensely help in reduction of loss due to flood. Awareness programme and training camps are being organised to make local communities capable of combating the flood situation. In Kashaphala, Bhograi,

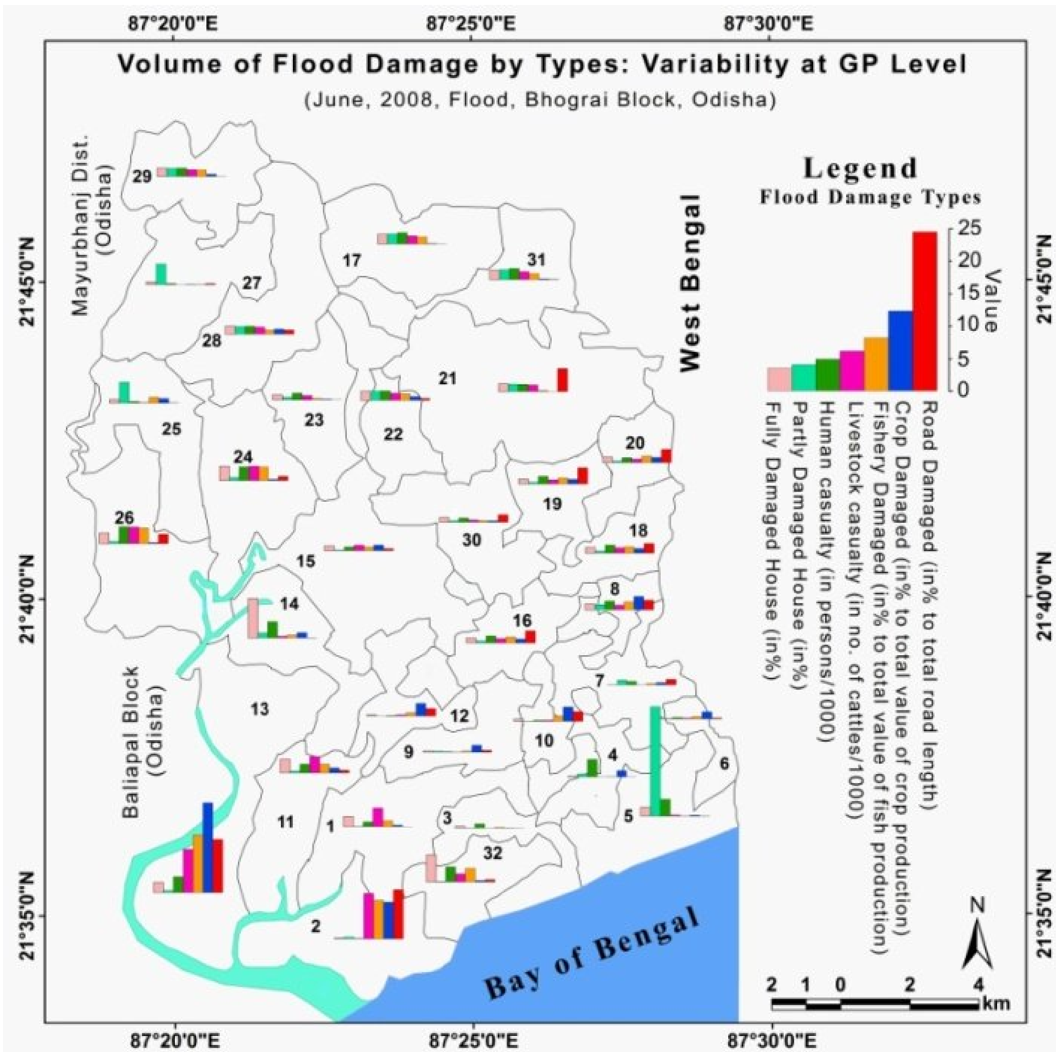

Fig. 3(a) Flood Impact Variability across Gram Panchayats

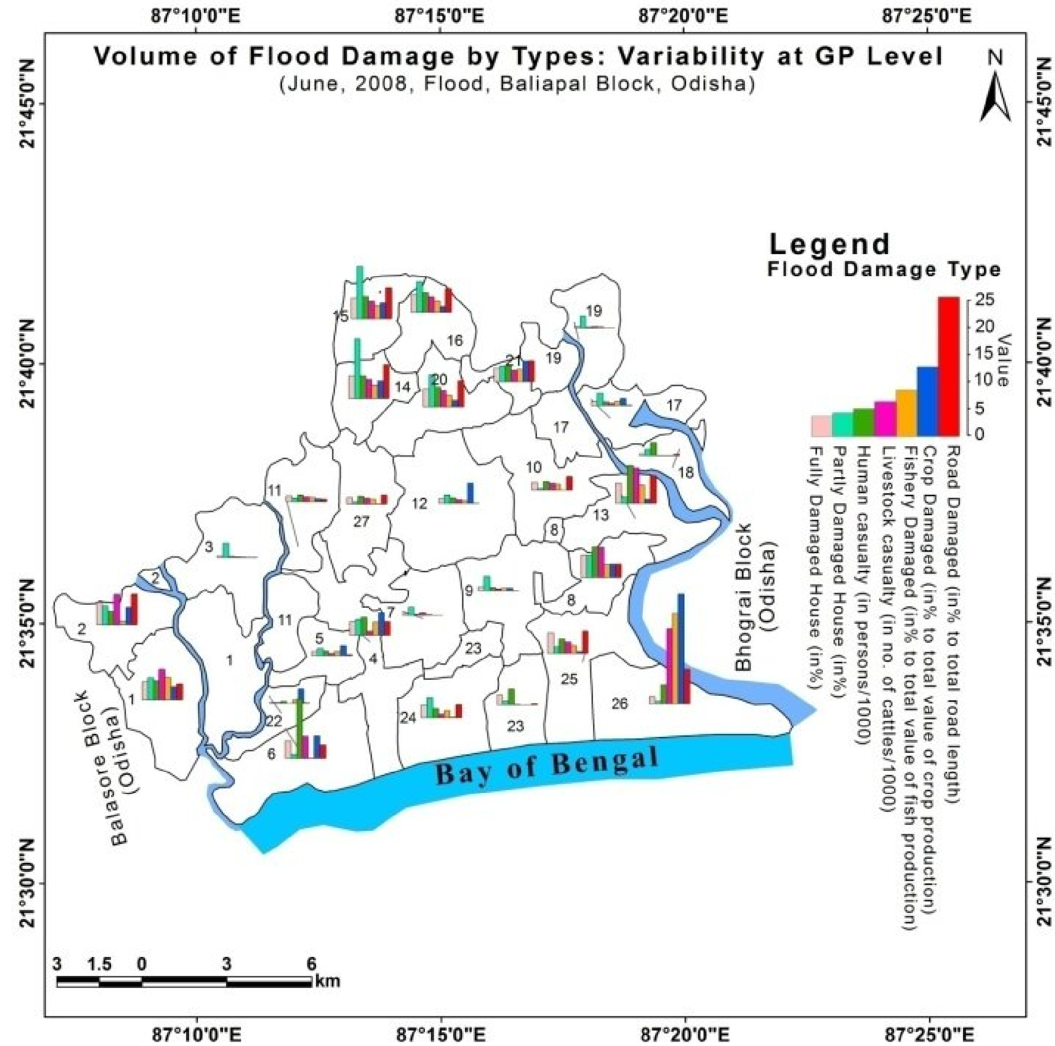

Fig. 3(b) Flood Impact Variability across Gram Panchayats

Nuagaon and Rasalpur-II GP, reverine embankments are heightened under National Rural Employment Guarantee Act programme. Above all, the floods and cyclones are now being predicted precisely by use of modern technology and preparedness has also been strengthened than ever before. All these have contributed largely in reducing the impacts of high intensity flood in many of the GPs of Balasore coastal stretch.

5. Conclusion

The Balasore coastal stretch, Odisha, India consisting of 3 coastal blocks with 86 Gram Panchayats along with a municipal area is located at the sea front on Subarnarekha delta plain. Due to its geomorphologically vulnerable situation, the area is laying face down to frequent flooding persuading by hazardous processes that organised both from land and ocean. Locational unevenness of flood hazard risk among the Gram Panchayats has been considered quantitatively considering the magnitude and the intensity in respect with the June, 2008 flood. Amalgamation of these two aspects of flood hazard along with its probability of occurrence yields the flood hazard score for each of the Gram Panchayats. The study evidently reveals that GPs having the location of river bank and sea front without any natural barrier

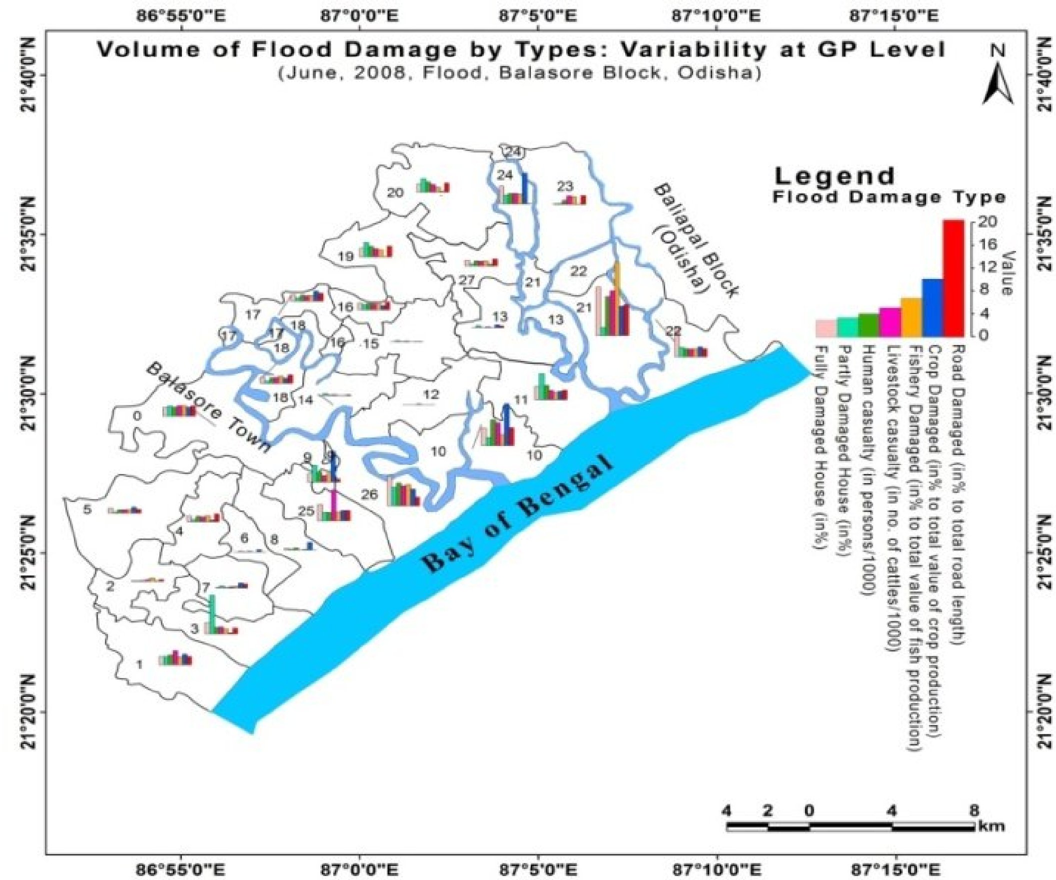

Fig. 3(c) Flood Impact Variability across Gram Panchayats

to protect the extreme events have high risk of flooding while GPs of interior location are in zone of lower risk. Gradually deteriorating capacity of river Subarnarekha, Dugdugi and Burahbalam to hold huge volume of water received from torrential rain of upper catchment has improved this flooding situation. In flow of tidal water along the river channel at the time of high magnitude discharge makes this situation more critical. Landfall with allied natural disturb like Storm surge, high astronomical tide has directed the ocean water to enter along tidal inlets that floods many of the GPs under study. Moreover, earthen boundary embankments of the fish ponds are also answerable for intensifying the flood situations. The study also gives light on protective measures against floods which have effectively reduced the damage impacts of even high magnitude floods. The GPs also vary with represent to types of damage caused by flood according to their locational entity.

Last of all the present study helps us to understand the causes, nature and types of flooding along with degree of flood hazard impacts at a rationally lower scale of geography. The study also helps to understand the varying nature of flood in different Gram Panchayats of the present study area. At the same time it has been proved that flood intensity is not always linearly dependant on physical severity of the flood. This type of study is helpful for taking GP specific planning decisions of flood management. Moreover, this study can be carried out in any coastal block for coastal hazard severity mapping and also for assessing risk associated with other coastal hazards along with the flood.

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