

# Flood vulnerability analysis and risk assessment using analytical hierarchy process

Kishor Dandapat<sup>1</sup>  · Gopal Krishna Panda<sup>1</sup>

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**Abstract** Paschim medinipur is one of the backward as well as highly flood prone district in the state of West Bengal, India. For many reason, the most frequent choice should be protection from the flooding by means of physical control of river. Though it is not possible to control the flood disaster totally. To minimize the flood damages analysis of flood vulnerability and risk assessment is an important strategy. For this work some physical and social variables has been selected who's potential to be harmed during the time of floods. While hazards are a potential threat to population and environment, risk is interplay between hazard and vulnerability. To evaluate the vulnerability analysis and risk assessment of flood, analytic hierarchy process and weighted linear combination has been used to functionalize the conceptual model within a GIS framework. To delineate the flood risk zones a composite vulnerability index map has been prepared which is accomplish with Physical Vulnerability Index, Social Vulnerability Index and Coping Capacity Index. Analysis revealed that 24.25% of the population lives in high to very high flood risk zones. Almost 17.76% of mud houses which are severe damage by floods located in high to very high risk zones.

**Keywords** Vulnerability · Risk · Analytical hierarchy process · Composite Vulnerability Index · Flood risk zonation

## Introduction

Paschim Medinipur district is one of the most vulnerable district as far as floods are concerned. The district has four river basins i.e. Kangsabati, Kaliaghai, Silabati and Subarnarekha. Kangsabati, Kaliaghai, and Silabati catchment are more vulnerability of flood then Subarnarekha. The floods have been distributed starting from the monsoon month of July to post monsoon month of October. Most devastating floods have been occurred in the month of October, September, August and July and their impacts had been so severe that it could be able to cripple the economy of the district. Most devastating floods occurred in the year of 1823, 1834, 1840, 1907, 1914, 1919, 1959, 1978, 1997, 2007 and 2015. The poor and marginalized people like the small and landless farmers, agricultural labourers and daily wage earners are most suffer by these events. The vulnerability analysis and risk assessment is recognised as an important tool to evolve disaster mitigation and preparedness plans in the hazard prone areas. For disaster prevention, mitigation and preparedness, it is important to identify vulnerable areas and factor configuring disaster risk where the impact could reach to severe magnitude for the affected communities. It is expected that the information will help preparedness planning and mitigation and for raising the level of awareness about the disasters in the community.

## Objective of the study

The main objective of the study to develop an approach for identifying, categorizing and quantifying elements at risk and their vulnerabilities to floods. Also analysis the people's vulnerability and risk in the flood plain area due to flood and coping strategies devoted by them.

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✉ Kishor Dandapat  
kishordandapat@gmail.com

<sup>1</sup> Department of Geography, Utkal University, Vani Vihar, Bhubaneswar 751004, India

## Location of the study area

Paschim Medinipur district, located in the Southern part of West Bengal, between  $22^{\circ}57'10''$  North and  $21^{\circ}36'35''$  North latitude and  $88^{\circ}12'40''$  E and  $86^{\circ}35'55''$  East longitude. Geographical area of the district is 9295 sq. km. The district is further divided into 4 sub-divisions, 29 blocks and 8 Municipalities (see Fig. 1).

## Concept of vulnerability and risk

The vulnerability describes the degree to which an area, people, physical structures or economic assets are exposed to loss, injury or damage caused by the impact of the hazard. Risk is viewed as the probability of occurrence or the degree of loss of a specified element expected from a specific hazard. Risk as the overlapping areas of three factors- hazard, exposure and vulnerability- that act simultaneously to generate the risk of natural hazards, which can be expressed as:

$$\text{Risk} = \text{hazard} \times \text{vulnerability} \quad (1)$$

$$\text{Risk} = \text{hazard} \times \text{exposure} \times \text{vulnerability} \quad (2)$$

while hazards are a potential threat to populations and the environment, risk is the interplay between hazard and vulnerability.

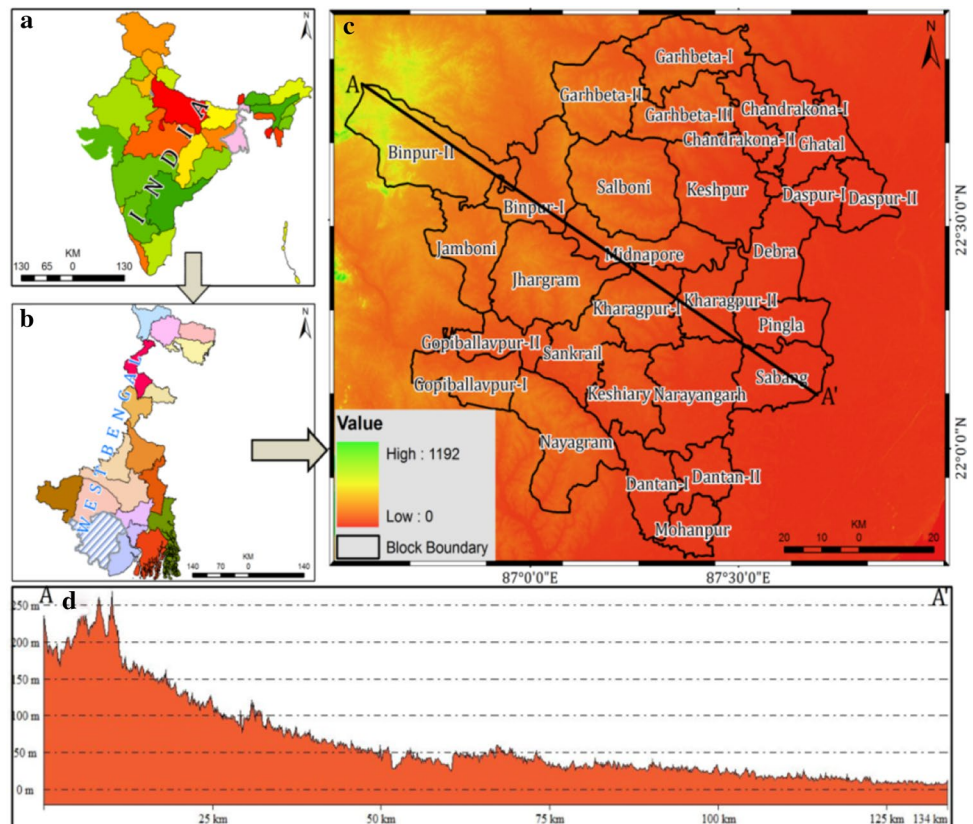
## Function of AHP

The hierarchical decision model is the design phase of AHP in which the top level exhibits the overall goal of the decision. Indicators can be criteria in the upper level of the model and each of them is further broken down into sub-criteria. Each pair of criteria or sub-criteria element is compared in terms of its relative importance using a 9-points system from 1 (if two indicators equally contribute to the objective) to 9 (when one indicator is strongly favoured over another to meet the objective), (see Table 1) and forms a comparison matrix namely, a pairwise comparison (see Table 2). A score of 1 denotes equal importance, a score of 3 refers to weak preference, while scores 5 and 7 represent obvious and strong preference. The even numbers (i.e., 2, 4, 6 and 8) are used when a compromise is needed between the odd numbers.

The local priority (weight) for a criterion is computed from a pairwise comparison matrix by normalizing the points in the columns (divide a cell value by the sum of a column) and averaging the normalized points in the row of the criterion. The consistency of the comparisons is evaluated by calculating a Consistency Ratio (CR). If the CR is equal to or less than 0.1, the comparisons are considered consistent, otherwise it would be revised. The CR is defined by the following equation:

$$\text{CR} = \text{Consistency Index} / \text{Random Index} \quad (3)$$

**Fig. 1** Geographical location of the study area



**Table 1** Semantic scale of the AHP method. Source: Ramanathan (2001)

Comparative importance	Definition	Description
1	Equal importance	Two indicators equally influence the parent decision
3	Weak importance	One factor is moderately influential over the other
5	Essential or strong importance	One factor is strongly favoured over the other
7	Demonstrated importance	One decision factor has significant influence over another
9	Absolute importance	Evidence favouring one decision factor over the other is the highest order of affirmation
2, 4, 6, 8	Intermediate	When compromise is needed, values between two adjacent judgments are used
Reciprocals	If $A_i$ is the judgemental value when $i$ is compared with $j$ , then $A_j$ has the reciprocal value when compared to $A_i$	A reasonable assumption

**Table 2** Example of a pairwise comparison matrix

Infrastructure and lifelines	Sources of water	Sanitation	Road density
Sources of water	1	3	4
Sanitation	1/3	1	2
Road density	1/4	1/2	1

The Random Index (RI) refers to a randomly generated reciprocal matrix from the 9-point scale and it can be obtained by referring to the RI table. Saaty (1980) provides a function of  $n$  in relationship (see Table 3). The consistency index (CI) is defined as:

$$CI = (\lambda_{max} - n) / (n - 1) \tag{4}$$

where,  $\lambda_{max}$  is the largest Eigen value derived from the comparison matrix and  $n$  is the number of criteria. A WLC is conducted by multiplying indicators by the corresponding weights and aggregating all weighted layers. In this study, the following equation was used:

$$VI = \sum_{i=1}^i \sum_{i=1}^i W_i W_{ij} x \tag{5}$$

where, VI is the Vulnerability Index for physical or social indicator,  $w_i$  and  $w_{ij}$  are the weights for the  $i$ th and  $j$ th sub-criterion and  $x$  represents the value of an indicator.

**Table 3** Random average consistency indexes for various  $n$

$n$	1	2	3	4	5	6	7	8	9
RI	0.0	0.0	0.58	0.90	1.12	1.24	1.32	1.41	1.45

' $n$ ' represent the number of criteria

### Data base and conceptual framework of methodology

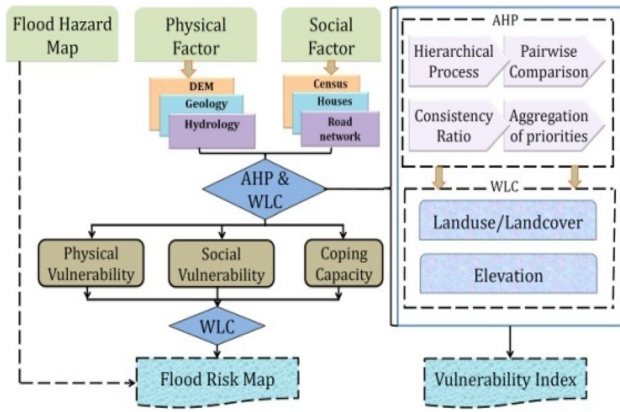
Data regarding physical vulnerability assessment were collected from a number of sources. An elevation data collected from SRTM dataset. Land-use and land-cover data obtained from the LISS 3 image and river network vector files/distance to active channel were collected from MBGIS. Geology data were collected from the geology map of Medinipur. To determine the indicators for social vulnerability and coping capacity, a range of variables was constructed from diverse sources. Socio-economic and demographic attributes were collected from the PHED, Govt. Of West Bengal and District Annual Plan, 2015–2016 which represent the population census of 2011.

Analytic hierarchy process (AHP) was first introduced by Thomas L. Saaty in the year of 1980. The AHP is based on multi-criteria that prioritize the criteria identified by different groups of people involved in the decision-making process in order to arrive at the best decision (see Fig. 2).

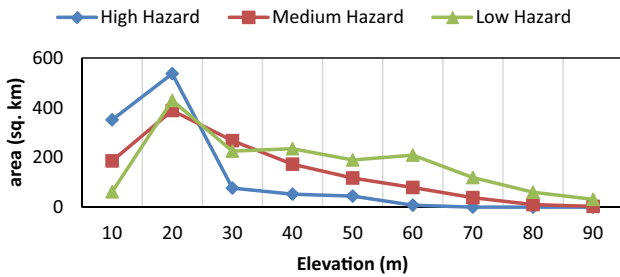
### Physical vulnerability analysis

#### Elevation

Elevation is the most important criteria because it has a tremendous effect on flood hazard in the study area, as most of the areas in southern and south-eastern part of the study area are low lying lands. As expected the high hazard category is less than 30 m. (see Fig. 3). Therefore, elevation of less than



**Fig. 2** Methodology flow chart showing the overall methods of the study



**Fig. 3** Elevation in each hazard zone, by area

**Table 4** Physical vulnerability decision hierarchy model

1	2		3	
	Criteria	Weight	Criteria	Weight
Physical Vulnerability Index	Elevation (m)	0.483	< 30	0.482
			30–60	0.299
			60–90	0.122
			90–270	0.064
			> 270	0.034
	Land-use category	0.316	Cultivated	0.483
			Rural settlement	0.261
			Built up area	0.141
			Vegetation and bare soil	0.074
			Wetland and water bodies	0.040
	Distance to active channel (k m)	0.145	< 0.5	0.470
			0.5–1.0	0.300
			1.0–1.5	0.160
			> 1.5	0.070
	Geology	0.056	Flood plain deposits	0.560
Sand with silts and clays			0.230	
Lalgarh formation			0.140	
Younger intrusive and DalmaVolcanics			0.070	

30 m. was given the highest weight, while elevation greater than 270 m. was assigned to the lowest weight (see Table 4).

**Land use and land cover**

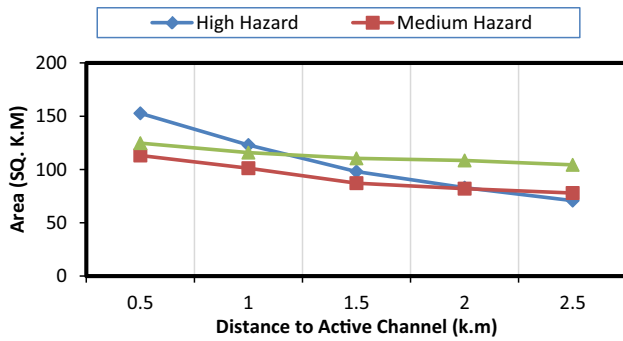
The land use and land cover data comprises of five categories namely, cultivated rural settlement, wetland and water bodies, vegetation and bare soils and built-up area. Since the potential effects of floods high for the cultivated category in terms of agricultural loss due to floods has a considerable impact on the rural people and also the local economy. That is the causes of cultivated category getting relatively highest weight (see Table 4).

**Distance to active channel**

People and property are in considerable danger up to 1.5 km away from the existing river networks. However, the maximum weight was allocated to the distance less than 0.5 km from the rivers and the lowest weight was given to the category with a distance greater than 1.5 km. (see Fig. 4; Table 4).

**Geology**

Geologically, the area can be divided into four categories. Younger intrusive and DalmaVolcanics is a highly elevated



**Fig. 4** Distance categories according to different flood hazard classes, by area

area and it is not usually inundated during the monsoon season. Therefore, it was assigned to the lowest weight. Flood plain deposit is areas where flood is a normal phenomena. This was given the highest importance followed by the sand with silts and clays category.

Regarding the importance of the criteria at the upper level (level 2), elevation was considered the most important criteria and given the highest weight. The second most important was given to land use category because consequent land use change is exacerbating river water flooding in the study area. Therefore, two other parameters, distance from the river and geology are given less importance in the second decision level (see Table 5). After deriving

**Table 5** Pairwise comparison matrix for physical indicators

	1	2	3	4	
<b>Criteria at level 2 of decision hierarchy model</b>					
1. Elevation	1	2	4	6	
2. Land-use	1/2	1	3	6	
3. Distance to active channel	1/4	1/3	1	4	
4. Geology	1/6	1/6	1/4	1	
CR: 0.05					
	1	2	3	4	5
<b>Criteria at level 3 of decision hierarchy model</b>					
<b>Land-use/land-cover</b>					
1. Cultivated	1	3	5	6	7
2. Rural settlement	1/3	1	3	5	6
3. Built-up area	1/5	1/3	1	3	5
4. Vegetation and bare soil	1/6	1/5	1/3	1	3
5. Wetland and water bodies	1/7	1/6	1/5	1/3	1
CR: 0.07					
<b>Elevation (m)</b>					
1. <30	1	3	5	7	9
2. 30–60	1/3	1	5	6	8
3. 60–90	1/5	1/5	1	3	5
4. 90–270	1/7	1/6	1/3	1	3
5. >270	1/9	1/8	1/5	1/3	1
CR: 0.08					
	1	2	3	4	
<b>Distance to active channel (k m)</b>					
1. <0.5	1	2	4	5	
2. 0.5–1.0	1/2	1	3	4	
3. 1.0–1.5	1/4	1/3	1	4	
4. >1.5	1/5	1/4	1/4	1	
CR: 0.07					
<b>Geology</b>					
1. Flood plain deposits	1	3	4	6	
2. Sand with silts and clays	1/3	1	2	3	
3. Lalgah formation	1/4	1/2	1	2	
4. Younger intrusive and DalmaVolcanics	1/6	1/3	1/2	1	
CR: 0.07					



the weights for each variable using the AHP, WLC was used. So all variables could be weighted and combined to derive a PVI. Before performing the WLC, the values for elevation and distance to active channels were standardized using the below equation:

$$\rho = \frac{\max - x}{\max - \min} \quad (6)$$

where, ‘ $\rho$ ’ is standardized value, min and max represent the minimum and maximum values for each dataset respectively and ‘ $x$ ’ is the cell value (see Fig. 5).

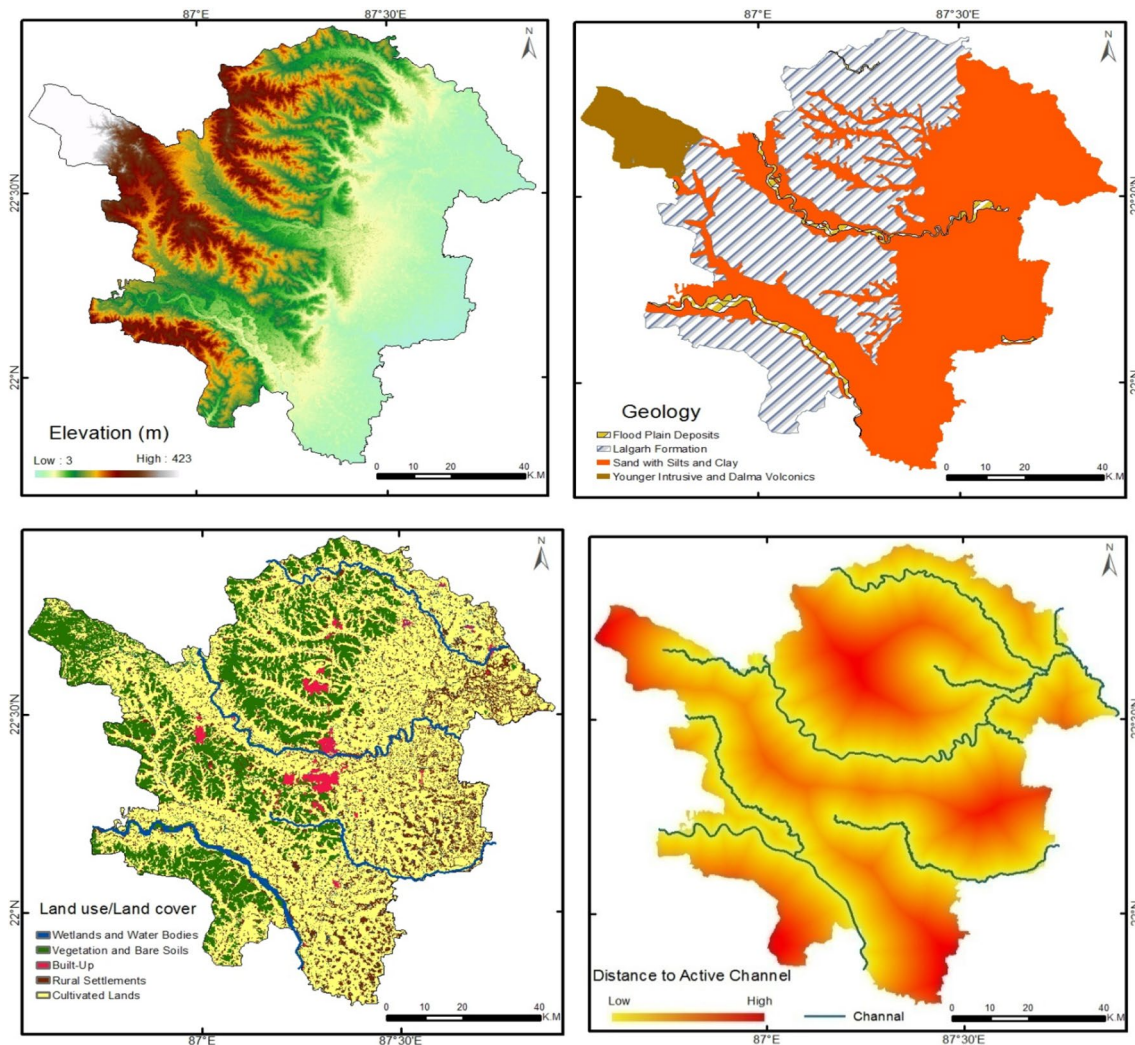
## Social vulnerability analysis

### Population density

Population density is regarded as one of the most important indicators in determining social vulnerability. Therefore, the indicator of population density was given higher importance at all levels of the decision hierarchy. Higher importance was allocated for higher density, while lower importance was given to lower density (see Table 6).

### Children and elderly population/dependent population

Age group of 0–14 and above 60 are generally dependent population and they are highly vulnerable to natural hazards because of their restricted mobility and difficulty with evacuation during emergencies (Cutter and Emrich 2009). A



**Fig. 5** Physical variables

total number of populations for these groups was extracted and classified into four categories: aged 0–4, 5–9, 10–14 and over 60. Children in the age group of 0–4 in the study area were given maximum weight in the lowest decision hierarchy (See Table 6) and the age group of 5–9, 60+ were given subsequent importance in the pairwise comparison (see Table 7).

**Gender**

Gender is an important consideration when depicting vulnerability to natural hazards (Cutter et al. 2003; Liverman 1990). Particularly in developing, moreover, most of the females in Paschim Medinipur district devote their lives to household activities from an early age and have fewer opportunities to participate in educational and social activities than males, making the female population highly vulnerable to natural hazards. Therefore, higher importance was

**Table 6** Decision hierarchy model for socioeconomic and infrastructure vulnerability

1	2		3		4	
	Criteria	Weight	Criteria	Weight	Criteria	Weight
Social Vulnerability Index	Demographic	0.567	Population density (km <sup>2</sup> )	0.619	< 400	0.05
					400–800	0.06
					800–1200	0.17
					1200–2400	0.25
					> 2400	0.47
			Age in year (dependent population)	0.284	0–4	0.597
					5–9	0.231
					10–14	0.047
					> 60	0.125
					Gender	0.097
	Socio-economic	0.320	B.P.L house hold/poverty (%)	0.484	Female	0.750
					< 7	0.053
					7–9	0.112
					9–11	0.253
					> 11	0.582
			Type of housing (%)	0.301	Katcha	0.690
					Semi-pucca	0.244
					Pucca	0.066
			Illiteracy (%)	0.143	< 15	0.036
					15–25	0.069
25–35	0.136					
35–45	0.262					
> 45	0.497					
Infrastructure and lifelines	0.123	Source of water	0.620	Tap water	0.063	
				Tube well	0.13	
				Well	0.388	
				Others	0.428	
				Sanitization (%)	0.240	Sanitized
		Road density (%)	0.140	No sanitation	0.688	
				Others	0.234	
				< 0.2	0.042	
				0.2–0.4	0.075	
				0.4–0.8	0.134	
0.8–1.6	0.264					
> 1.6	0.485					

**Table 7** Pairwise comparison matrix for social vulnerability indicators

	1	2	3		
Criteria at level 2 of decision hierarchy model					
Components					
1. Demographic	1	2	4		
2. Socio-economic	1/2	1	3		
3. Infrastructure and lifelines	1/4	1/3	1		
CR: 0.01					
Criteria at level 3 of decision hierarchy model					
Demographic					
1. Population density (km <sup>2</sup> )	1	3	5		
2 Age	1/3	1	4		
3. Gender	1/5	1/4	1		
CR: 0.08					
Socio-economic					
1. Illiteracy	1	1/4	1/3		
2 B.P.L households	4	1	2		
3. Type of housing	3	1/2	1		
CR: 0.02					
Infrastructure and lifelines					
1. Sources of water	1	3	4		
2. Sanitation	1/3	1	2		
3. Road density	1/4	1/2	1		
CR: 0.02					
	1	2	3	4	5
Criteria at level 4 of decision hierarchy model					
Population density (km <sup>2</sup> )					
1. < 400	1	1/2	1/4	1/6	1/7
2. 400–800	2	1	1/3	1/5	1/6
3. 800–1200	4	3	1	1/3	1/5
4. 1200–2400	6	5	3	1	1/3
5. > 2400	7	6	5	3	1
CR: 0.063					
Road density (km <sup>2</sup> )					
1. < 0.2	1	1/3	1/4	1/6	1/7
2. 0.2–0.4	3	1	1/3	1/5	1/6
3. 0.4–0.8	4	3	1	1/3	1/5
4. 0.8–1.6	6	5	3	1	1/3
5. > 1.6	7	6	5	3	1
CR: 0.068					
Illiteracy rate (%)					
1. < 15	1	1/3	1/5	1/7	1/8
2. 15–25	3	1	1/3	1/5	1/7
3. 25–35	5	3	1	1/3	1/5
4. 35–45	7	5	3	1	1/3
5. > 45	8	7	5	3	1
CR: 0.063					
	1	2	3	4	
Age in year (dependent population)					
1. 0–4	1	4	8	4	



**Table 7** (continued)

	1	2	3	4
2. 5–9	1/4	1	5	3
3. 10–14	1/8	1/5	1	1/4
4. >60	1/4	1/3	4	1
CR: 0.08				
Poverty (%)				
1. <7	1	1/3	1/5	1/8
2. 7–9	3	1	1/3	1/6
3. 9–11	5	3	1	1/3
4. >11	8	6	3	1
CR: 0.04				
Water sources				
1. Others	1	1	5	6
2. Well	1	1	4	5
3. Tube well	1/5	1/4	1	3
4. Tap water	1/6	1/5	1/3	1
CR: 0.04				
	1	2	3	
Type of housing				
1. Pucca	1	1/5	1/8	
2. Semi-pucca	5	1	1/4	
3. Katcha	8	4	1	
CR: 0.08				
Sanitation				
1. Sanitized	1	3	4	
2. Others	1/3	1	2	
3. No Sanitation	1/4	1/2	1	
CR: 0.07				

given to females in the gender variable (see Figs. 6, 7, 8, 9; Table 6).

**Poverty**

The linkage between hazards, vulnerability and poverty are complex (Few 2003); however, many studies assert that low-income people suffer the most from natural hazards (Dasgupta 2007). Higher importance and subsequent weighting were allocated to the greater proportion of poor people in each community and the lowest weight given to the lowest proportion (see Table 6).

**Types of housing**

Most of the houses in rural area are katcha type and many houses built on floodplains and in close proximity to water bodies tend to exhibit greater vulnerability. Three types of housing information are available in the study area: katcha, semi-pucca and pucca. These housing types were incorporated into the vulnerability evaluation. As katcha houses are

poor in quality and subject to severe damage from floods, they were given higher Weight (see Table 6) than the other two categories in the pairwise comparison matrix (see Table 7).

**Illiteracy**

The number of illiterate population (males and females) was used with the assumption that illiterate people are dependent on others to prepare and evacuate themselves during a forthcoming disaster. Thus, the highest illiteracy rates of the district were given the highest importance when allocating weight in the decision hierarchy (see Table 6).

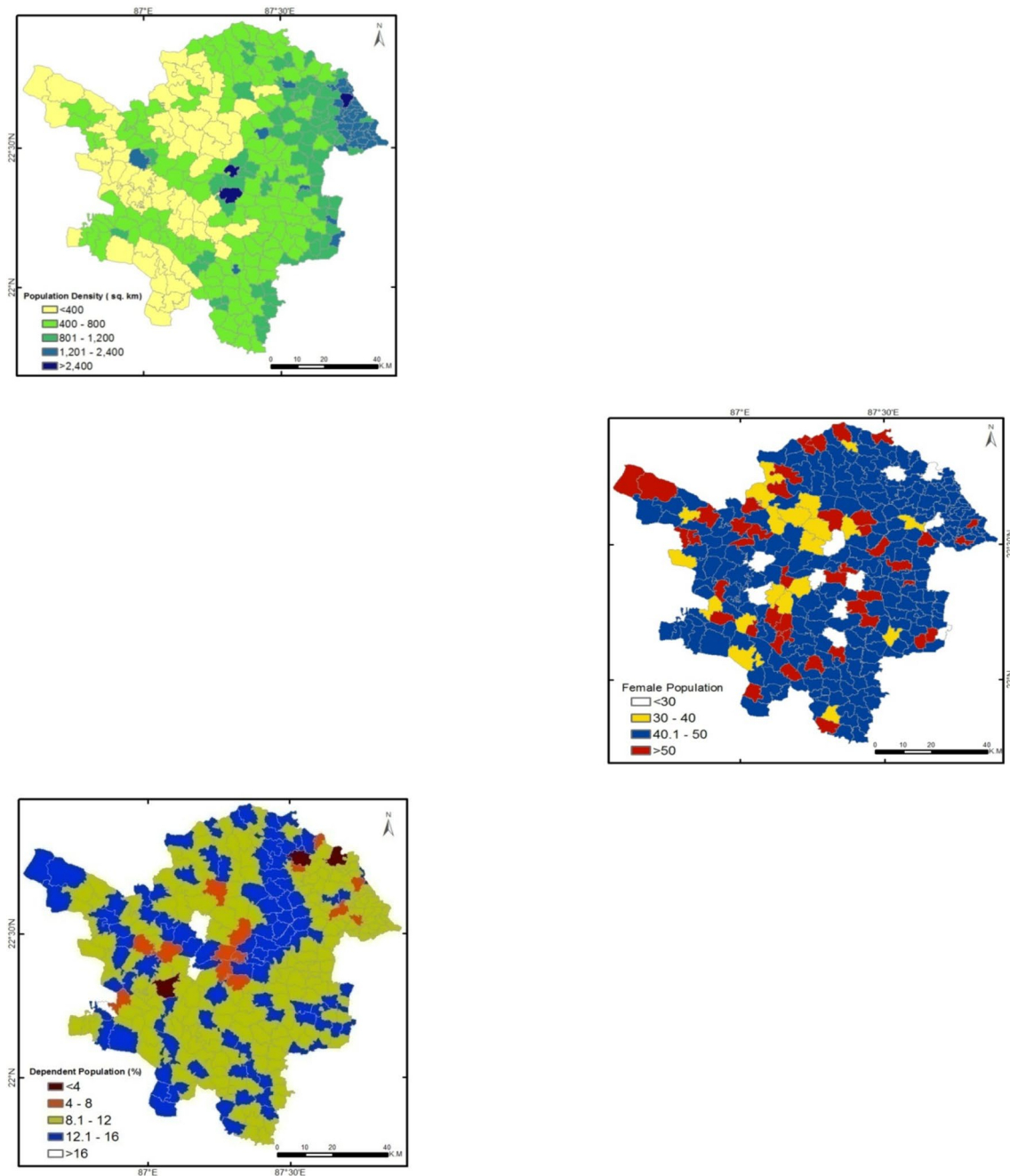
**Sources of water**

Mixing of drain water well water also polluted in the time of flood. So drinking water exceeded standard limits and pure drinking water becomes scarce in the time of floods. There are a number of water sources for drinking purposes namely; taps, tube wells, wells, ponds and rivers are available in the

study area. Therefore, other water sources received the highest weighting, as people relying on this source like to be at a greater risk of water-borne disease. Well, tube well and tap water’s weights were allocated with subsequent importance (see Table 6).

### Sanitation

The sanitation of Paschim Medinipur district is not encouraging, as thousands of people are at risk of communicable diseases after a flood event. The no sanitation category was given the most weight, followed by the other mean of sanitation (see Table 6).



**Fig. 6** Distribution of Demographic Indicators

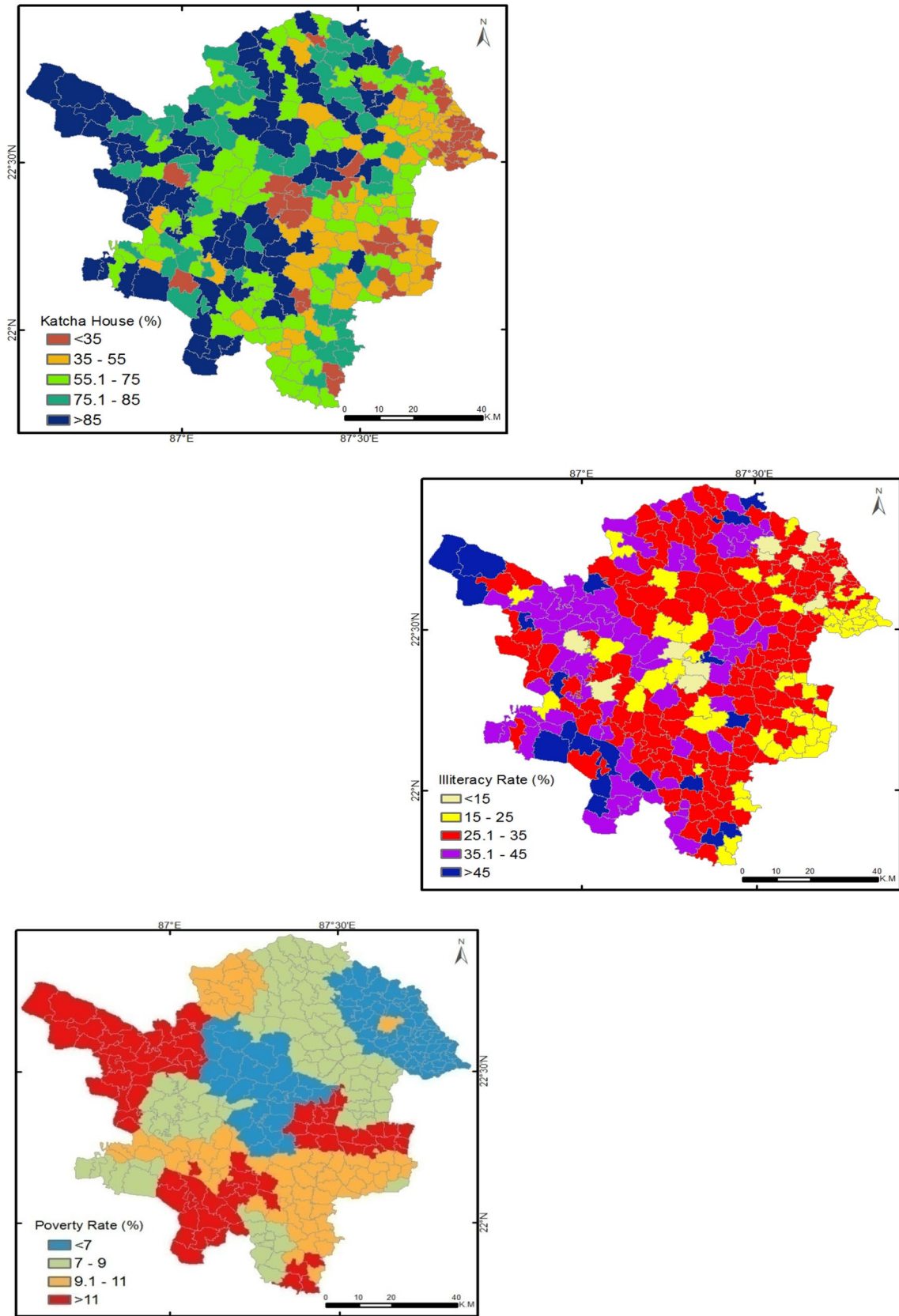


Fig. 7 Distribution of socioeconomic indicators

**Road density**

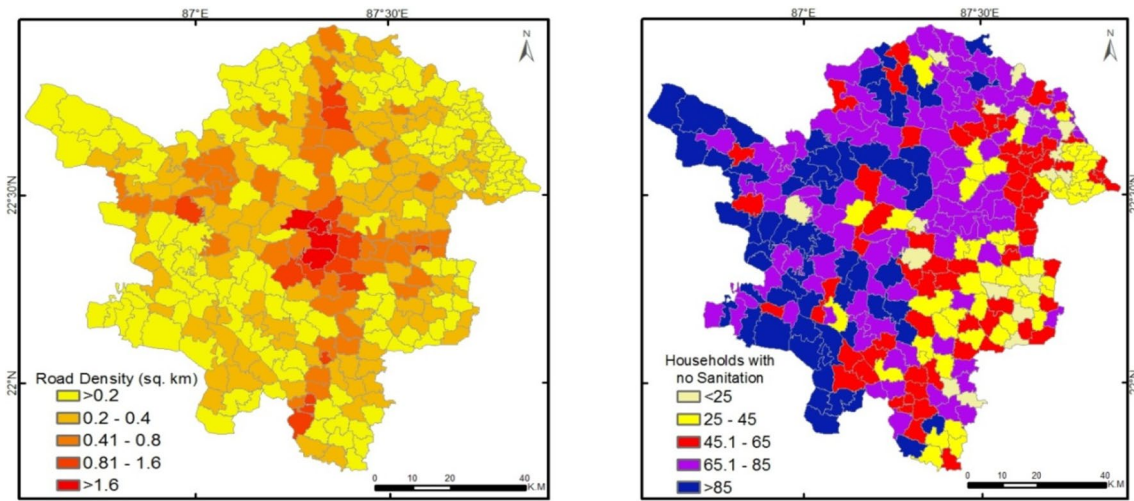
Infrastructure facilities such as roads and rail networks are in the category of “lifeline” and play a significant role in evacuation and post event relief and recovery. As these networks are important in determining the lifeline of a community, the density of roads was calculated from the Geo-Eye image with the GP boundary and weighted using the AHP (see Table 6).

Table 7 represents the pairwise comparison matrices for demographics, socioeconomic and infrastructure and lifeline criteria with their corresponding consistency ratios. The census values for the indicators were first converted into ratios

from count and subsequently the weights were assigned to the ratio. The normalization was then performed using the following equation:

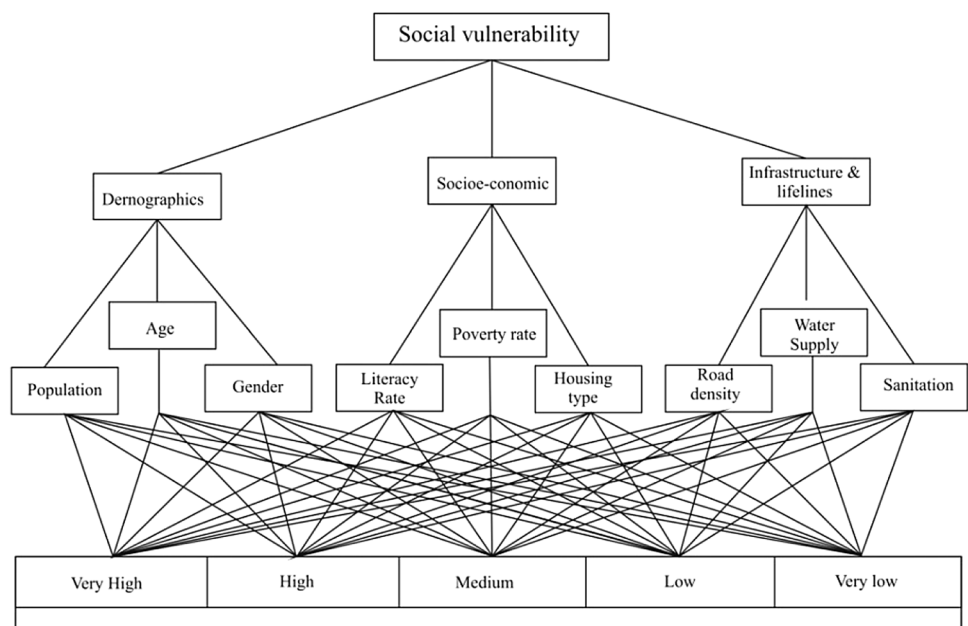
$$S = \frac{\max - x}{\max - \min} \tag{7}$$

where, S is the normalized value, min and max represents the minimum and maximum values of the indicator variable respectively and ‘x’ is the weighted value of the community. The derived social vulnerability index (SVI) indicated that the higher the value, the greater the vulnerability of a particular community.



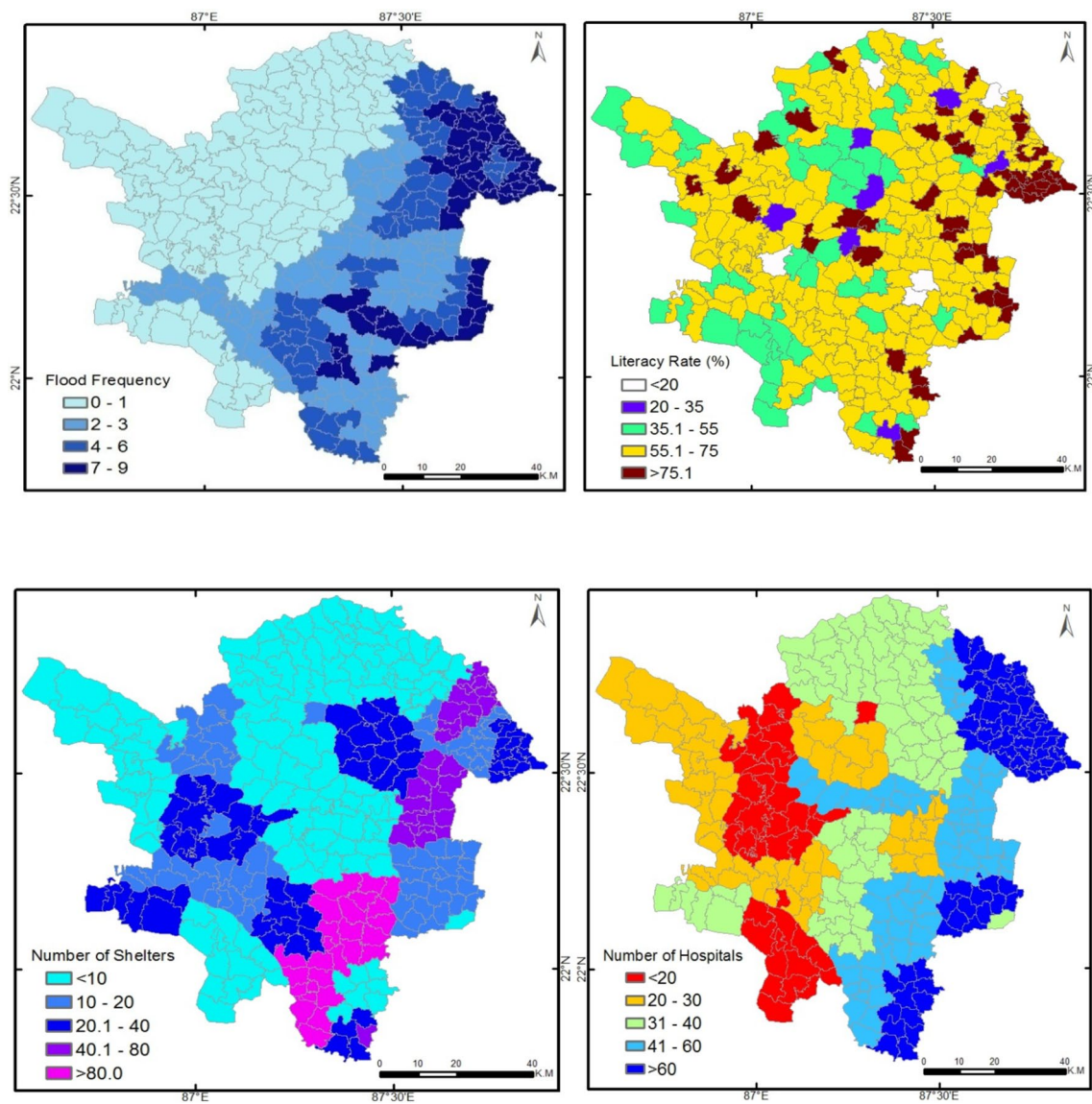
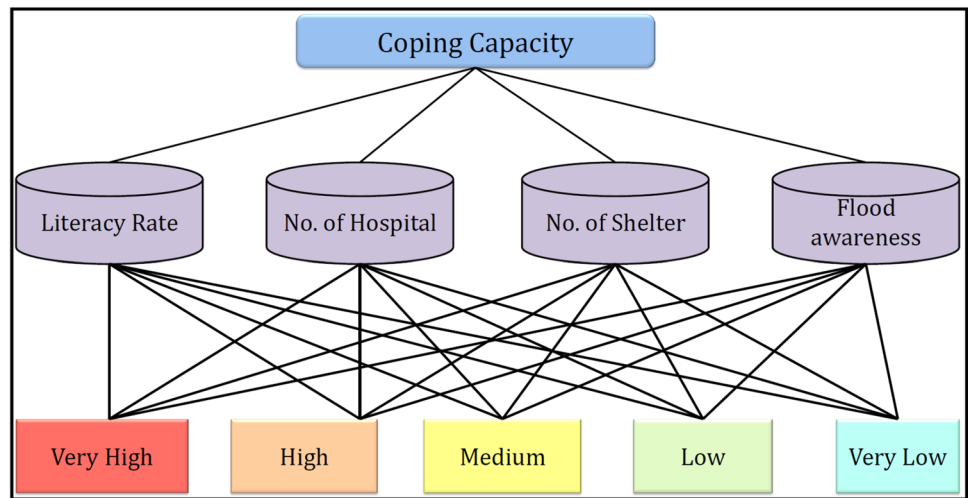
**Fig. 8** Distribution of lifeline and infrastructure indicators

**Fig. 9** Decision hierarchy model for social vulnerability assessment





**Fig. 10** Decision hierarchy model for coping capacity analysis



**Fig. 11** Distribution of coping capacity indicators

### Coping capacity analysis

The selected indicators for coping capacity analysis are the total literacy rate, per capita hospitals, per capita flood shelters and flood awareness (see Figs. 10, 11), as shown in the decision hierarchy model (see Table 8). For these indicators, higher importance was given to the sub-criteria, with higher values in the pairwise comparison computation (see Table 9) so that areas with better coping capacity could be mapped.

#### Flood awareness

The classic natural hazard paradigm shows that prior experience of hazards plays a crucial role in mitigating the negative consequences of floods and preparing against disaster (Paul 1997). Therefore, the flood frequency variable was derived by overlaying multi-temporal flood maps from 2011, 2013, 2015 and 2016 which are collected from BHUVAN disaster series and on the community database. The highest weight was given to this variable among other coping capacity variables in the second level of the decision hierarchy, as disaster preparedness is an important factor for a community to cope with natural disaster. A pairwise comparison matrix prepared for Coping Capacity Index (CCI) by AHP method.

### Literacy rate

Education is an important human wealth that allows people to make appropriate decision and take pertinent mitigation measure to withstand or recover from natural disaster (D’Oyley and Blunt 1994). It also affects people’s lifetime earnings (Cutter et al. 2003). Literature suggests that households with higher levels of education cope better than households with lower level of education (Paul and Routray 2010). To examine this proposition, the total literacy rate was used and weighted for each community to assist in understanding their coping capacity (see Table 8). The highest weight was assigned to communities with the highest literacy rate for both males and females, and lowest weight was assigned to those with lower literacy rate.

#### Per capita shelters and hospitals

The availability of shelters and health-care facilities in hazard-prone areas is a vital indicator of coping capacity of a particular community. A database containing the locations of educational institutes, community, religious centres and different medical facilities calculate as the per capita shelters and hospitals in the study area. The higher the numbers of shelters and hospitals in each community, the higher the weight in terms of the third level of the decision hierarchy; however, the highest weight was given to the per capita shelter indicator in the second level of the decision hierarchy (see Table 8).

**Table 8** Decision hierarchy model for coping capacity criteria

1	2		3	
	Criteria	Weight	Criteria	Weight
Coping Capacity Index	Flood frequency (awareness)	0.582	0–1	0.062
			1–3	0.108
			4–6	0.267
			7–9	0.563
	Literacy rate (%)	0.238	< 20	0.040
			20–35	0.074
			35.1–55	0.142
			55.1–75	0.248
			> 75.1	0.496
	No. of hospitals (%)	0.070	< 20	0.038
			20–30	0.054
			31–40	0.137
			41–60	0.280
			> 60	0.491
No. of shelters (%)	0.110	< 10	0.039	
		10–20	0.056	
		20.1–40	0.134	
		40.1–80	0.269	
		> 80	0.502	



The resulting Coping Capacity Index (CCI) indicates that the higher the index, the better the coping capacity of a particular community.

### Derivation of Composite Vulnerability Index (CVI)

A composite vulnerability map was produced by combining vulnerability and coping capacity maps using WLC

technique. An equal weighting scheme was adopted for this purpose (Cutter et al. 2003). To combine three maps and estimate CVI, first of all, mean PVI score for each community was derived by intersecting it with the community boundary file. Then, the CCI was linearly inversed so that the lower the CCI value, the higher the contribution of a particular community to flood vulnerability. The following equation was used to derive the overall vulnerability or CVI:

$$CVI = 0.33 \times PVI + 0.33 \times SVI + 0.33 \times CCI \quad (8)$$

**Table 9** Pairwise comparison matrix for coping capacity indicators

	1	2	3	4	
Criteria at level 2 of decision hierarchy model					
1. Flood frequency (awareness)	1	4	5	6	
2. Literacy rate	1/4	1	3	4	
3. No. of shelters	1/5	1/3	1	2	
4. No. of hospital	1/6	1/4	1/2	1	
CR: 0.05					
	1	2	3	4	5
Criteria at level 3 of decision hierarchy model					
Literacy rate (%)					
1. < 20	1	1/3	1/5	1/6	1/7
2. 20–35	3	1	1/3	1/4	1/7
3. 35.1–55	5	3	1	1/3	1/5
4. 55.1–75	6	4	3	1	1/3
5. > 75.1	7	7	5	3	1
CR: 0.07					
No. of flood shelters (%)					
1. < 10	1	1/2	1/5	1/7	1/8
2. 10–20	2	1	1/3	1/6	1/8
3. 20.1–40	5	3	1	1/3	1/5
4. 40.1–80	7	6	3	1	1/3
5. > 80	8	8	5	3	1
CR: 0.05					
No. of hospitals (%)					
1. <20	1	1/2	1/5	1/7	1/8
2. 20–30	2	1	1/4	1/6	1/8
3. 31–40	5	4	1	1/4	1/5
4. 41–60	7	6	4	1	1/3
5. > 60	8	8	5	3	1
CR: 0.07					
	1	2	3	4	
Flood frequency (awareness)					
1.0–1	1	1/2	1/5	1/7	
2. 1–3	2	1	1/3	1/5	
3. 4–6	5	3	1	1/3	
4. 7–9	7	5	3	1	
CR: 0.03					

It should be noted that the inversed  $CCI = \max - CCI$ .

## Flood risk assessment

A flood risk map is one of the most important measures for preventing flood loss potential (Yoshino and Yoshikawa 1985). A flood risk map based on fine spatial units (e.g., at the community level) is particularly useful for planners and emergency managers when developing appropriate counter measures. Flood risk is defined in this study as a function of flood hazard and vulnerability (Apel and Aronica 2009). The following equation is used to derive flood risk map in the study area (Fig. 12):

$$\text{Flood Risk} = \text{hazard} \times \text{vulnerability} \quad (9)$$

## Results and discussion

### Physical vulnerability

The PVI map revealed that areas closer to water bodies or near to river with a low elevation (< 5 m.) constitute higher vulnerability to flood (see Fig. 13). Due to their low elevation and close proximity to river networks communities in these areas are highly susceptible to extreme flood loss also (see Table 10). For instance, more than 50% of the population is vulnerable with respect to their locational attribute, as mean distance from active channels. In study area Southern and South-eastern part are in the high to very high vulnerable zones (0.82–1.00) in terms of locational and demographic characteristics. In south-eastern direction Ghatal sub-division are highly affected by recurrent flood due to absolute locational factor and also in terms of densely populated and productive nature of the soil. A small percentage of population (2.02%) is in the very low physical vulnerability zone because these zone is highly altitude (> 90 m). So, those are the locational factor is an important indicator in estimating flood vulnerability in Paschim Medinipur District.

### Social vulnerability

The SVI map revealed that some of the Eastern, Southern and South-eastern directions of the study area are in the low (0.24–0.36) to very low (0–0.23) social vulnerability in respect of less poverty, high literacy and lower percentage of katcha houses, implying that people in this zone are able to absorb losses relatively quickly. Very high social vulnerable zone (0.78–1) are distributed along the south and

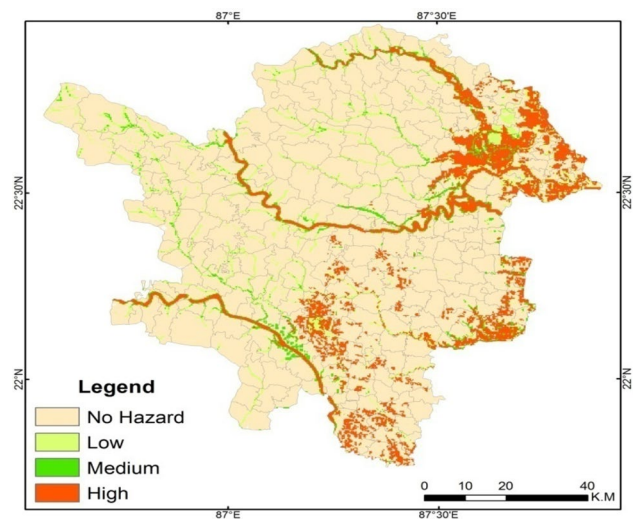
south-eastern margin and also northern and north-western part of the study area. Table 11 explains that the social vulnerability of high and very high vulnerable zones is due to high levels of poverty, a large number of katcha houses and high population density. In contrast, access to safe water and sanitation is very low, suggesting a degree of vulnerability to floods. The resulting map also revealed that few communities in western and middle part of the study area very low social vulnerability (0–0.23).

### Coping capacity

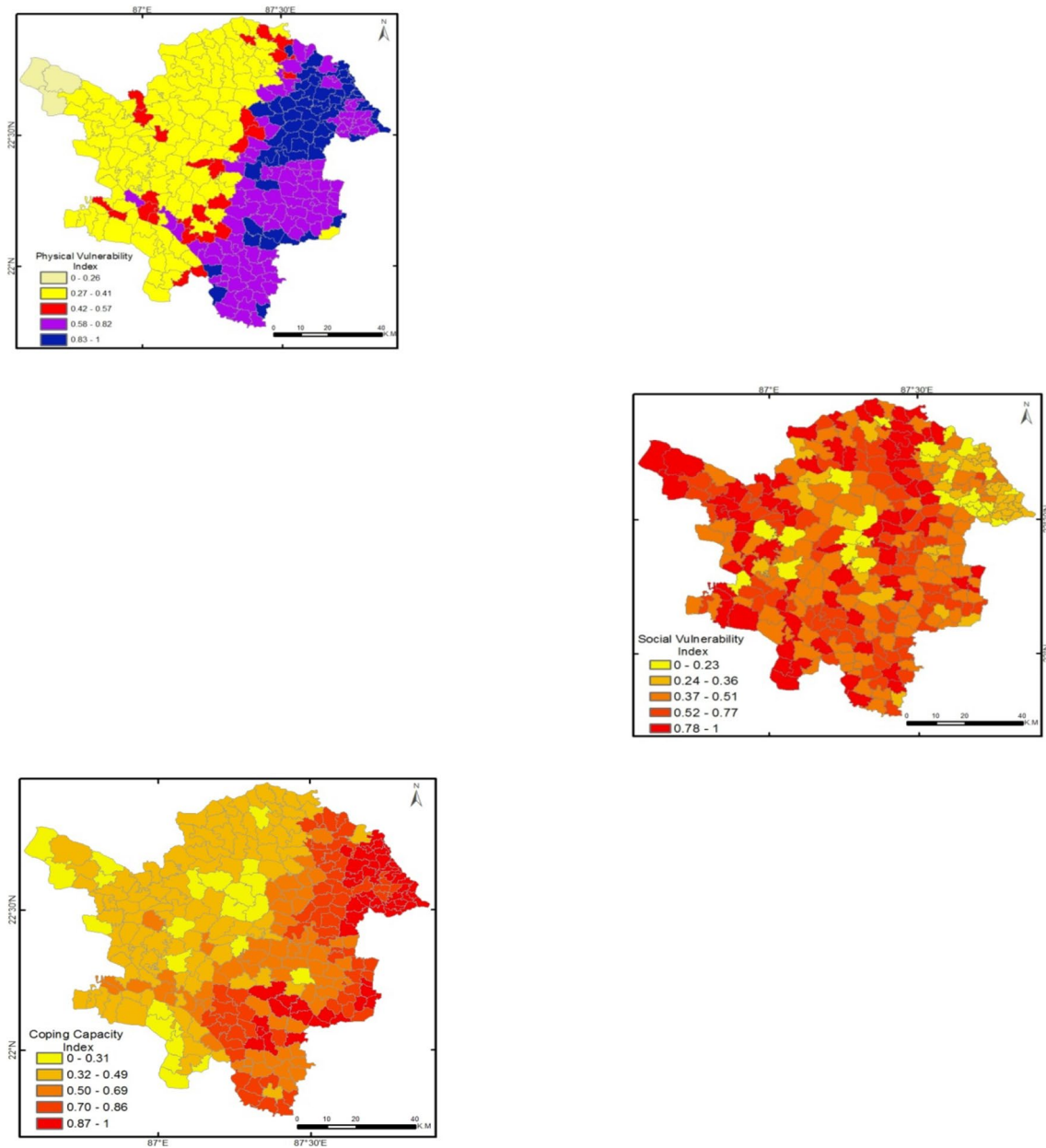
A coping capacity map showed different results compared to those of vulnerability maps, partly because of the integration of the flood awareness variable into the derivation of the coping capacity of communities. However, a coping capacity indicator can be conceptualized as a form of the adaption capacity of individuals or a community in the study area (Few 2003). Communities that experience floods almost every year exhibit a very high coping capacity (> 0.87) and which communities did not experience floods in a regular way, they exhibit a very low coping capacity (< 0.31).

### Composite vulnerability

This study conceived that the coping capacity is part of vulnerability assessment (UNDP 1992) and should be included in the estimation of the overall vulnerability of



**Fig. 12** Flood hazard map



**Fig. 13** Spatial patterns of physical and social vulnerability and coping capacity

**Table 10** Distribution of variables in relation to physical vulnerability

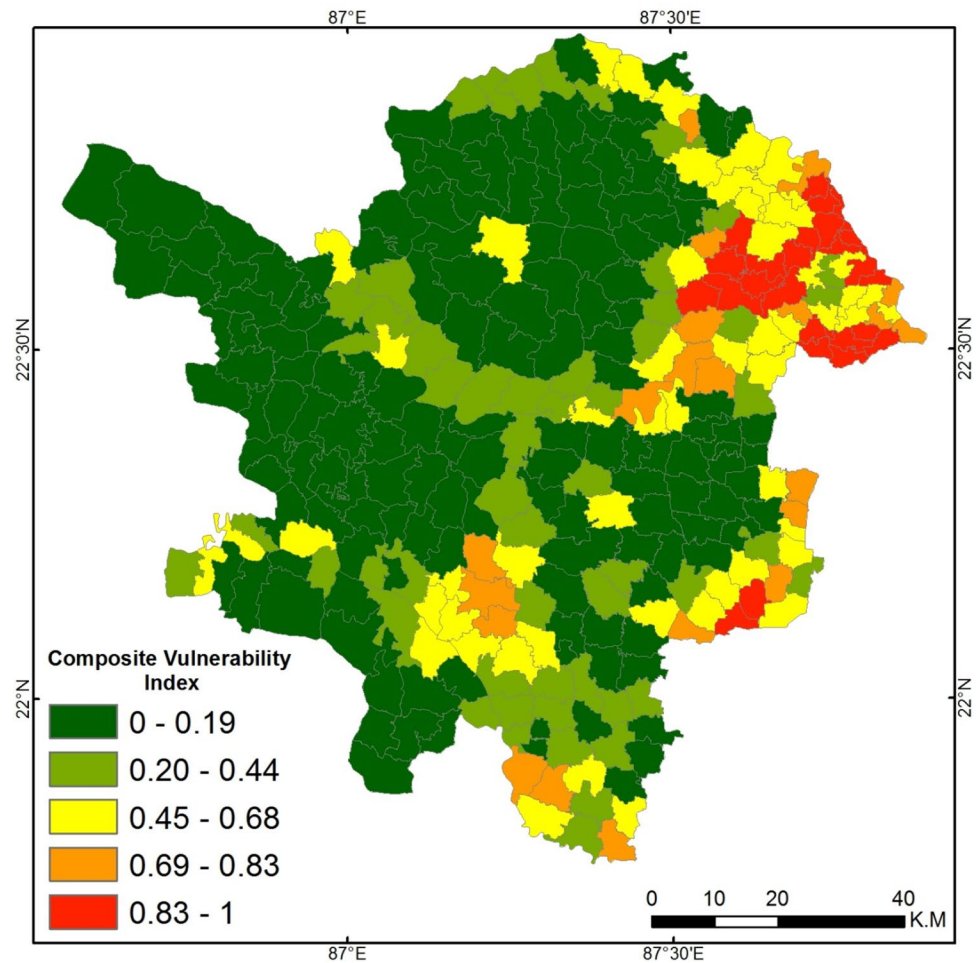
PV Zone	Value	Population (%)	Mean elevational range (m)	Mean distance to active channel (k m)
Very low	0–0.26	2.02	> 90	2
Low	0.27–0.41	37.33	60–90	1.8
Medium	0.42–0.57	8.33	30–60	1.5
High	0.58–0.82	32.09	5–30	0.8
Very high	0.82–1.00	20.57	< 5	0.5

a particular area. A CVI was therefore mapped out by combining PVI, SVI and CCI (see Fig. 14) and further reclassified according to the severity of vulnerability. The population distribution in each zone indicated that 27 and 15% of people are located in the high and very high zones of vulnerability respectively. The percentage of katcha houses, which are usually home of poor people, is higher in the very high vulnerable zone (39%) (see Table 12).

**Table 11** Distribution of variables regarding the SVI

SV zone	population Density (sq km)	Poverty (%)	Katcha Houses (%)	Water Sources			Sanitation	
				Tap (%)	Tube well and well (%)	Pond and others (%)	Sanitized (%)	Others and no Sanitation (%)
Very low (0–0.23)	34750.64	6.05	4.08	15.8	2.09	4.1	10.4	2.5
Low (0.24–0.36)	34175.73	11.10	24.42	52.1	16.2	20.1	39.7	30.6
Medium (0.37–0.51)	49960.2	18.94	30.93	25.7	38.21	35.0	33.8	30.0
High (0.52–0.77)	46444.42	29.07	24.46	4.2	18.0	16.4	7.1	21.5
Very high (0.78–1.00)	54297.26	34.84	16.10	2.1	25.5	24.4	9.0	15.9

SVI social vulnerability

**Fig. 14** Spatial pattern of Composite Vulnerability Index

### Flood risk mapping

Flood risk map was derived by multiplying the mean hazard score and composite vulnerability map. While hazard represent physical process, flood vulnerability indicates susceptibility to damage and the risk of human lives. To understand the human dimensions of flood risk, population and other parameter were intersected with the derived risk map

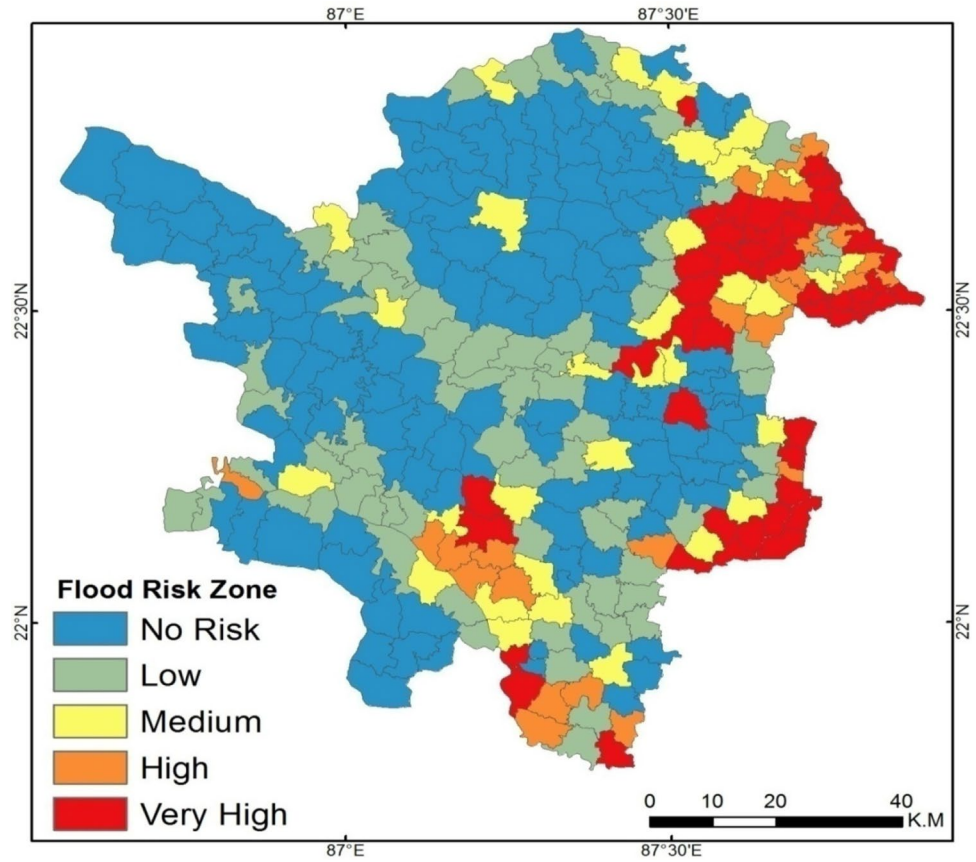
and statistical analysis was conducted. Most of the elevated places have been no risk and low elevated areas are likely to be higher at the risk spectrum (see Fig. 15).

Using population census data from 2011 and the socio-economic distribution, Table 13 summarizes vulnerable subgroups into different flood risk zones. A total of 24.25% of the population lives in high to very high flood risk zones, which is further compounded by the number of females,

**Table 12** Distribution of variables relating to CVI

CVI zone	Value	Population (%)	Katcha houses (%)	Semi-pucca (%)	Pucca (%)	Mean literacy rate
Very high	0.83–1	15.3	38.5	9.3	14.2	78.6
High	0.69–0.83	27.2	29.3	37.4	21.1	68.5
Medium	0.45–0.68	24.5	15.7	30.7	27.2	60.2
Low	0.20–0.44	20.00	9.04	15.6	23.1	58.1
Very low	0–0.19	13.00	7.1	7.0	14.4	49.6

**Fig. 15** Flood risk map



**Table 13** Distribution of variables in different flood risk zones

Flood risk zone	Population	%	Male	%	Female	%	Young (0–14)	%	Illiterate	%	Mud house	%
Very high	966,277	17.02	519,505	16.46	439,511	17.42	157,230	16.76	245,643	13.72	2332.73	11.84
High	410,365	7.23	213,701	6.77	202,664	8.04	47,382	7.53	114,355	6.39	1166.9	5.92
Medium	433,798	7.64	310,635	9.84	279,225	11.07	74,998	10.3	173,684	9.7	1997.4	10.14
Low	1,510,312	26.6	806,865	25.56	516,964	20.49	166,582	25.46	462,907	25.85	5187.44	26.33
No risk	2,358,131	41.52	1,305,657	41.37	1,084,156	42.98	255,095	40.12	794,253	44.35	9017.95	45.77

young (0–14), elderly (> 60) and illiterate people. At least 17.76% of housing units (mud house) are located in high to very high risk zones. As noted earlier, the study is based on 2011 census data and does not take into account potential population growth in the study area, which may underestimate the actual population at risk. However, the flood risk map developed can be used as base line information for the development of adaption measures to mitigate future losses driven by flood hazard.

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