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Flood Risk Assessment and Its Mapping in Purba Medinipur District, West Bengal, India

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Abstract: Floods are one of the most common quasi-natural hazards in costal districts of West Bengal, India and thousands of people are affected every year. From the destruction of crop lands and buildings to the disruption of balance of the environment and the spreading of disease, floods can devastate entire regions. The risk of flood depends on the flood intensity, frequency, and duration, the vulnerability of the people, etc. The spatiality of flood risk is still insufficient at micro level study for the management of resource disasters. In consequence, the present study on 'flood risk mapping' is performed in Purba Medinipur (one of the coastal districts of West Bengal, India) by considering the flood frequency and vulnerability of the people as flood risk components. The frequency of floods from 2002 to 2019 is considered as a variable of assessment and twenty-five key indicators are employed to understand the vulnerability of the people of the region. From the analysis, Moyna emerges as the highest flood risk prone block and Contai-I is the least flood prone block of the district. The results can help to minimize the chances of death, injury, loss, or harm and establish a good disaster management plan against floods.

Keywords: pluvial flood; flood frequency; vulnerability; risk assessment; principal component analysis (PCA)

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1. Introduction

All the low lying, populated areas of the tropical world are in flood risk condition and are frequently flooded by both natural and anthropogenic causes [1]. In recent decades, the frequency and impact of extreme flood events have rapidly increased worldwide [2]. Floods involve a wide range of disruptions in basin ecology and introduce different types of threats into people's lives [3–5]. Flood incidents are caused by heavy rain, cyclonic events, and riverbank or coastal erosion under the influence of climatic variability. The pluvial flood is very common, especially in the vast flood plain areas of tropical monsoon. The presence of river channel acts as an exposure and increases the risk of flood. From the viewpoints of hazards, vulnerability, exposure, and capacity (United Nations Office for Disaster Risk Reduction (UNISDR) [6], risk of flood can be assessed.

Korn [1], Rasch [7] and Luu, et al. [8] state that the risk of flood is basically interlinked with three components, i.e., vulnerability, exposure, and hazard. Similarly, Jha and Gundimeda [9] explain that flood vulnerability depends on exposure, sensitivity, and adapted capacity. Exposure and sensitivity work as positive factors (they increase flood risk) and adapted capacity acts as a negative factor (it decreases flood risk). Tang et al. [10] find that flood risk is an outcome of flood hazard, exposure, and sensitivity and adaptive capacity. In recent years, attempts at spatial analysis using geospatial techniques have occupied a prominent place in identifying flood risk zones and the social impacts of floods. Some researchers [11–16] use remote sensing data and a Geographic Information System (GIS) to formulate the risk. Ciaravino and Ciaravino [17] and De Wrachien et al. [18] explain that risk is the expected damage and it is a function of hazard, exposition, and vulnerability during the time of flood. Kaya et al. [19] mention that flood risk is greatly dependent on surface topography and land utilization features.

The assessment of social vulnerability to identify flood risk zones is also considered a very popular approach which has been adopted by several authors. Mavhura et al. [20], Török, [21], Chakraborty et al. [22], and Tascón-González et al. [23] use this method to identify the vulnerable communities exposed to flood hazards. Very high vulnerability to floods indicates extreme probability of loss in both socio-economic and physical environments [24]. Densely populated regions have an increased vulnerability to floods. Rasch [7] mentions that residents of municipalities without piped water and sewage disposal systems are at a higher risk of floods due to dehydration and water-borne illness. Education enhances the level of awareness and increases the chances of residents obtaining jobs and moving out of the risky areas, which reduces the level of vulnerability [25]. Thus, all the vulnerability indicators, positive or negative, influence the risk of floods. So, the parameters of vulnerability are very important for flood risk zone identification and its risk management.

In India, 12.5% of areas are considered as flood prone [26]. After Bangladesh, India is the second most flood-affected country in the world [27]. In West Bengal (an eastern state of India), 42.4% of the total geographical area, or stated in another way, 69% of its net-cropped area, has been affected by an inundation situation (as reported by the West Bengal Disaster Management & Civil Defence Department). As a coastal region district, Purba Medinipur (erstwhile Midnapore), which is located in the southern part of West Bengal along the coast tract of Bay of Bengal, is flood prone as several coastal storms approach this area regularly. Besides, 75–80% of the total annual rainfall during the monsoon season in the form of siltation, small catchment area, and water release from Mukutmanipur dam, DVC (Damodar Valley Corporation) barrage, etc. is the main cause of flood in Purba Medinipur. Almost every block of this coastal district has experienced inundation at the time of the south-west monsoon from the middle of June to September. The Purba Medinipur district suffers minor to major floods almost every year. In 1956, 1959, 1978, 1995, and 2000 floods submerged a large, low lying part of the district. The flood of September, 2000 is known as the Millennium Flood in Bengal [28]. Due to this flood, 72,610 houses were fully damaged and 99,900 hectares of farmland and around 1 million people were badly affected. Eleven people lost their lives in the Purba Medinipur, Paschim Medinipur, and Jhargram districts (as mentioned by the Department of Disaster Management, Government of West Bengal).

Very few studies have been performed in the Purba Medinipur district that discuss the identification of flood prone area, risk assessment, disaster management, etc. Barman et al. [29] analyze the water logging scenario due to tidal flood and rain-water flood in the Khejuri-I and Khejuri-II blocks (two eastern blocks of the Purba Medinipur district). Das and Sahu [30] identify flood prone mouzas of the Panskura block (northern side block of the Purba Medinipur district) using GIS techniques and evaluate the scenarios of flood periodicity, seasonality, and spatio-temporal variations while also grouping the affected mouzas. Kaur et al. [31] develop a quantitative predictive model of flood susceptibility for the Tamluk sub-division of the district. However, no such flood risk assessment work has been performed at block level in the Purba Medinipur district. Gayen et al. [32] identify the most vulnerable blocks in the Purba Medinipur district by employing three different standardization methods and compare the obtained results among the blocks; however, the impact of extreme hydrological vulnerability on a particular hazard has not been discussed systematically. In response to this limitation, the aim of the present case study is to construct the block wise flood risk zone map of the Purba Medinipur district depending on the flood hazard frequency and indicators of vulnerability. Flood risk zone identification is done by multiplying the hazard and vulnerability score through a flood risk index developed by Tchórzewska-Cieślak et al. [33], Jelínek et al. [34], and Aguirre-Ayerbe et al. [35].

2. Materials and Methods

2.1. Data Consideration for the Flood Risk Assessment

The present work is based on the block wise frequency of flood events of the last eighteen years (2002 to 2019) in the jurisdiction of Purba Medinipur district. The data were collected from the state Disaster Management & Civil Defense Department, Government of West Bengal. The disaster management plan of Purba Medinipur district (different years) is another source of data on flood scenarios. The effort regarding the flood frequency mapping is the most important factor for the flood hazard assessment. Major and medium floods were counted to prepare the flood frequency map. Monthly rainfall data for the same period were used to understand the rainfall pattern of the district. Rainfall data were obtained from District Statistical Handbooks (2005–2015) [36] of Purba Medinipur and from Annual Flood Report of (2002–2019) [37] of West Bengal. block wise secondary data like population density, child population, etc. were collected from Census of India (2011) [38], to assess the vulnerability.

2.2. Assessment of Extreme Geo-Hydrological Condition in the Study Area

2.2.1. Location

Purba Medinipur district was chosen as a study area as it is one of the most flood prone districts of West Bengal (advocated by West Bengal Disaster Management & Civil Defence Department) and it underwent severe flood disaster events in last two decades. The district is located between 21°36′35″ N and 22°57′10″ N latitudes and 86°33′50″ E and 88°12′40″ E longitudes and is part of tropical monsoon climate. The average elevation of the district is 10 m above the mean sea level. The district has 25 community development blocks and five municipalities (Figure 1). The headquarters of the district is located in Tamluk urban center.

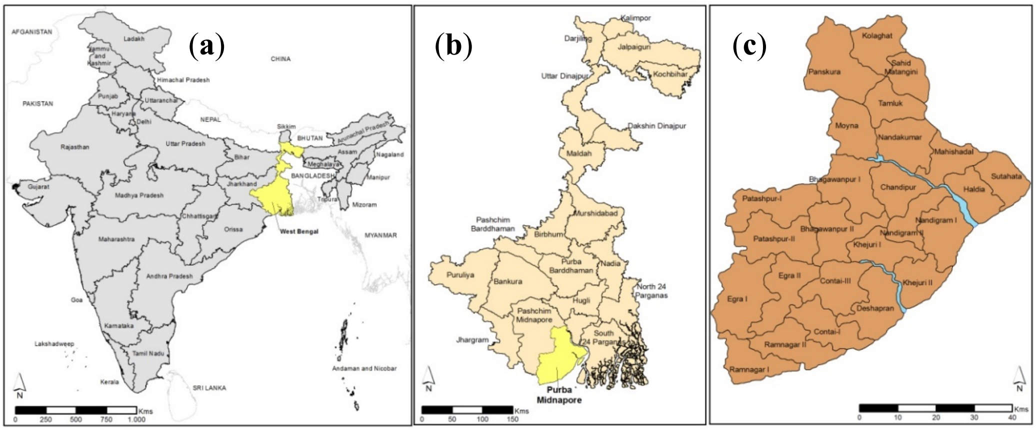

Figure 1. Geographic location map of the study area. (**a**) Map of India showing different states. The state of West Bengal is highlighted in yellow. (**b**) Map of West Bengal showing different districts within the study area; Purba Medinipur district is marked in yellow. (**c**) Map of study area; Purba Medinipur district (block wise).

2.2.2. Rainfall

The rainfall graph (Figure 2) shows the average rainfall (2002–2019) of different months of the year. The average yearly rainfall (2002–2019) of the district is 1671.79 mm. Winter season corresponds to the months of December, January, and February and those are generally dry months. In winter, sometimes occasional rainfall happens due to the Western Disturbances. Some rainfall occurs in April and May from the storm of Kalbaisakhi, which is a thunderstorm with rainfall in the Gangetic plains of West Bengal.

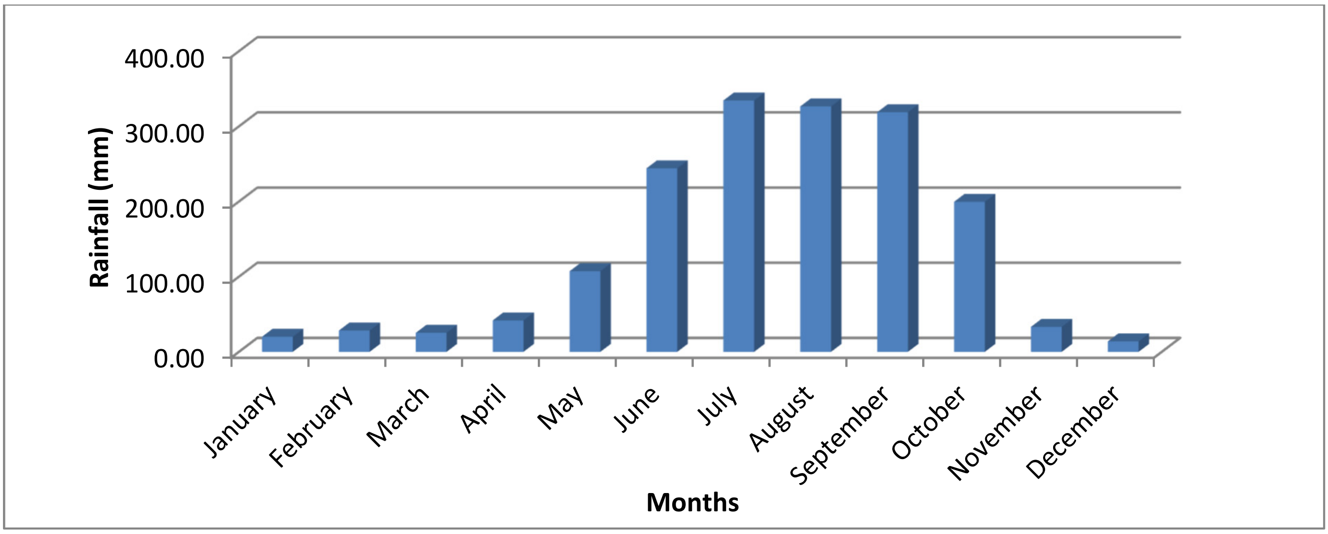

Figure 2. Average rainfall of the Purba Medinipur district (2002–2019).

The rainy season starts in the district in the middle of June and ends in the middle of September. Most vulnerable floods are seen in these four months. The district experienced six extreme tropical cyclones since 2011. At the end of October, few cyclonic storms develop due to the formation of low-pressure trough on the Bay of Bengal. These cyclonic storms are known as Ashwiner Jhor, and can also be the cause of floods.

2.2.3. Drainage System

All the rivers of Purba Medinipur district flow from north-west to south-east according to slope of the region (Figure 3). Kaliaghai, Rupnarayan, Haldi, and Rasulpur are the main rivers of the district. Kanshabati river (also known as the Kasai or Cossye) originates from the Chhota Nagpur Plateau in the Purulia district and flows south-eastward. After bifurcation, the southern course, known as New Cossye, flows to further south-easterly direction. Keleghai river originates from Dudhkundi of Jhargram district and flows toward the south-east. It joins the New Cossye river near Dheubhanga and forms Haldi river. Rupnarayan joins the Hugli river near Geyokhali in Purba Medinipur district. This river forms the eastern boundary of Purba Medinipur district with the district of Howrah. The towns of Kolaghat and Tamluk are located on the riverbank of Rupnarayan. Rasulpur river is the last tributary of Hugli river. The length of this river is only 19 km. It is the main drainage channel of Contai sub-division. It flows as Bagda river until Kalinagar and after that it is known as Rasulpur river. Its tributaries are Itaberia Khal and Mugberia Khal. All rivers mostly have tidal effect twice a day and experience tidal-bore during the rainy season.

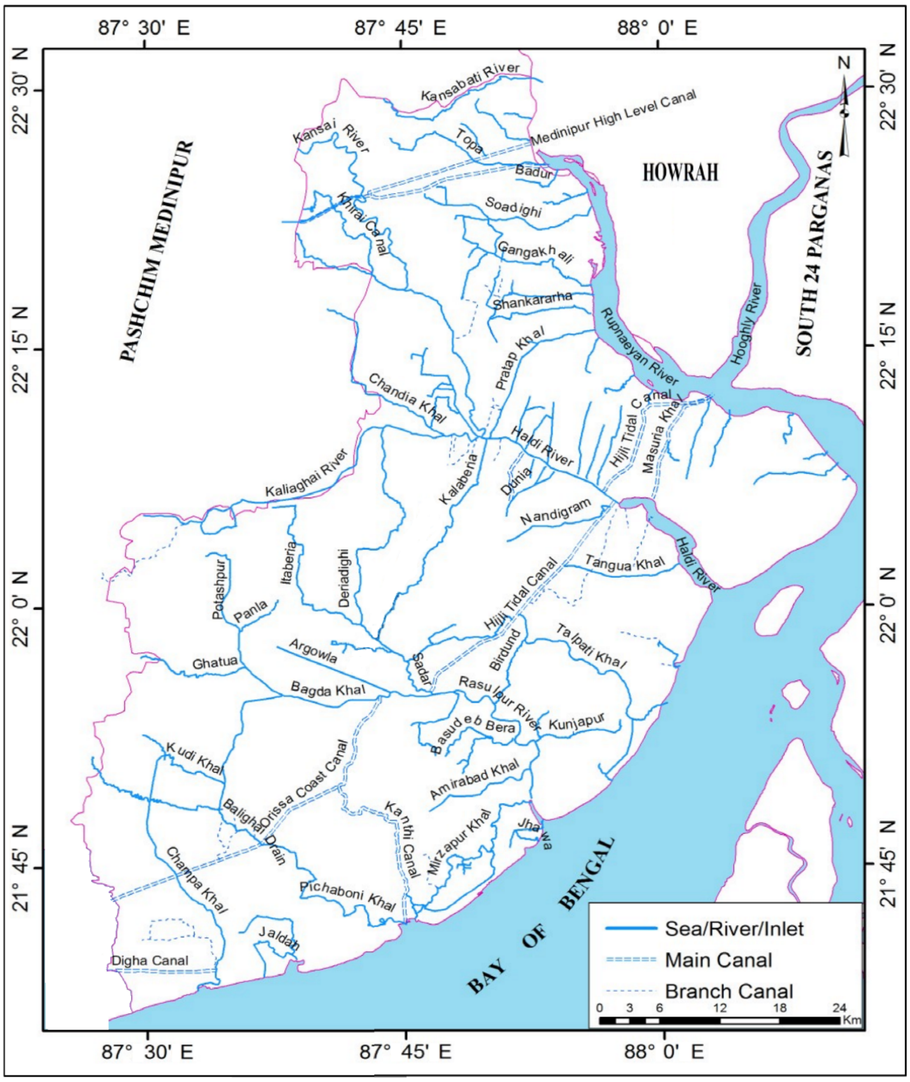

Figure 3. River map of Purba Medinipur district. Source: District Environment Plan (Purba Medinipur).

2.3. Assessment of Flood Risk in the Study Area

Risk is the probability of expected losses of inhabitants by the interaction between hazard and their vulnerable conditions (International Strategy for Disaster Reduction (ISDR) [39]; United Nations Development Programme (UNDP) [40]; Wisner et al. [3]). The probability of risk is varied from one community to another community. The potentiality of risk is not the same for different hazards even in the same region or in the same community and thus risk was determined by two components: hazard and vulnerability [41].

According to ISDR [39], the equation of risk is

$$R = H \times V \quad (1)$$

where, R is risk, H is hazard, and V is vulnerability. Here, Equation (1) is used to understand the flood risk in the case study of Purba Medinipur district. Pistrika and Tsakiris, [42] and Cançado et al. [43] also used this equation in the flood risk assessment study. Thus, if there is no hazard in any region, following the above equation, the risk of this region is zero. Figure 4 shows the conceptual model of flood risk assessment applied in this study. Before calculation of the flood risk, it is necessary to know the existing adopted score of hazard and vulnerability in the study area.

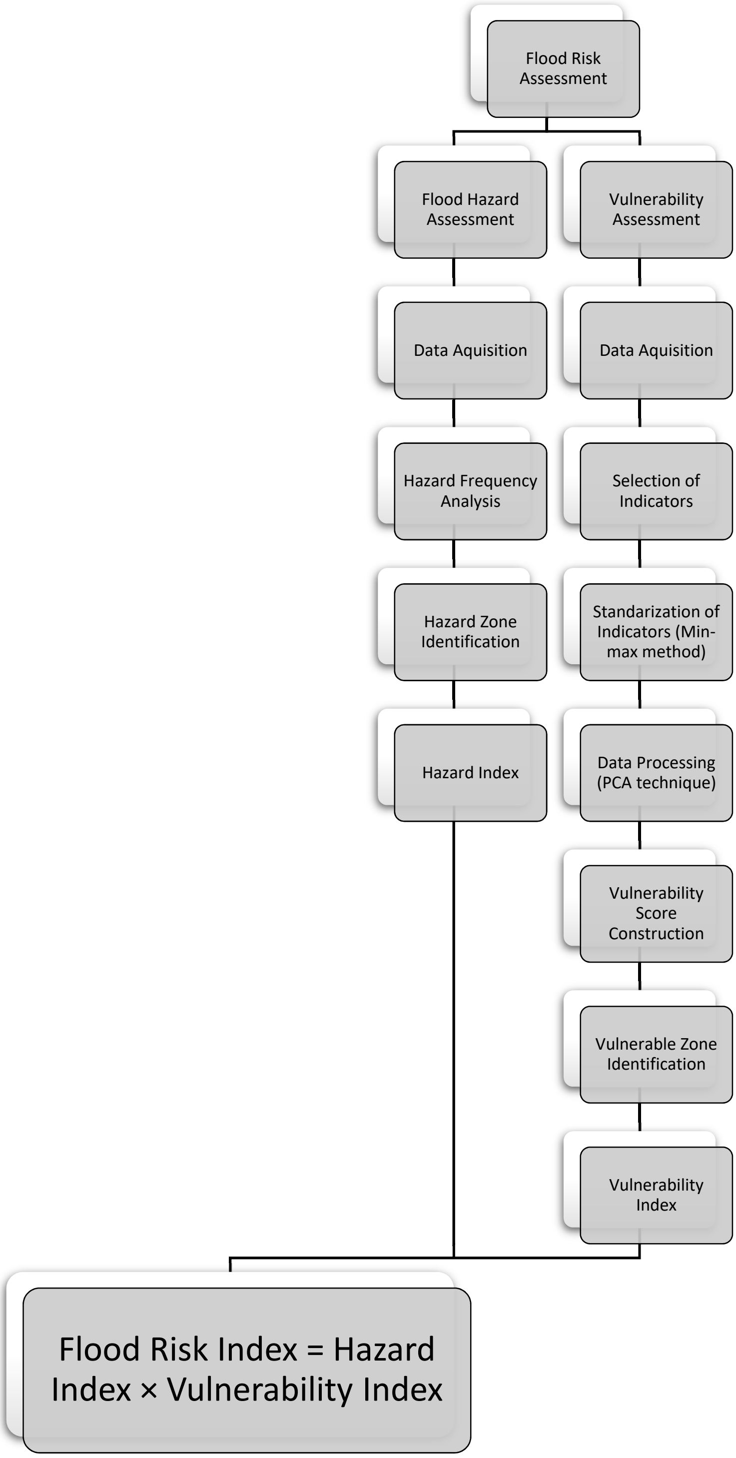

Figure 4. Conceptual framework of adopted research design for flood risk assessment in the study area.

2.3.1. Flood Hazard Assessment

Hazards are potential damaging events, phenomena, or actions that may cause loss of life, injury, property damage, socio-economic disruption, and environmental degradation with the propagation of its development. In this study, flood hazard was measured by the repetition of inundation conditions. Flood frequency analysis is a technique that advocates the occurrence of a flood in a particular span of time. Owing to its unique hydro-geomorphological characteristics, the vast area of the district has recurring inundation with varied magnitude. In the present study, the inundation condition was segmented into three groups, i.e., large floods which have devastating nature and require relief and support, medium floods which lead to agricultural failure, and small floods which show the simple inundation condition. To measure the flood frequency in the study area, all the large and medium floods as recognized by district administration were considered. Comparatively large floods occur less frequently than medium and small floods. In this study, the number of floods that occurred between 2002 and 2019 were considered as flood frequency for each block. The idea of flood frequency is used here to predict the structural failure by flood event along the riverbank, like damage to buildings, roads, highways, embankments, etc. Analysis of flood frequency also helps engineers design safeguards to prevent structures from being damaged and protects against economic losses.

Flood hazard index (FHI) is an indicator used to explain the different intensity or frequency of a flood in a particular geographical setting. Using the hydrological model and statistical methods in GIS platform, the FHI was calculated by Asare-Kyei et al. [44] and the resultant value of FHI varied from 1 (very low flood hazard intensity) to 5 (very high flood hazard intensity). Kabenge et al. [45] used geoinformation based FHI for the Nyamwamba watershed in Uganda. In the present work, resultant values of FHI were classified into five different categories, i.e., very low, low, medium, high, and very high and weighted values were defined as 1, 2, 3, 4, and 5 respectively (Table 1).

Table 1. Flood hazard index.

Frequency of Flood (in Eighteen Years)	Hazard Classes	Hazard Index
<6	Very low	1
6–7	Low	2
8–9	Medium	3
10–11	High	4
>11	Very high	5

2.3.2. Vulnerability Assessment

Vulnerability assessment is an integral part of flood risk analysis [46]. Reduction of vulnerability is a core element in reducing disaster-related risk and it was identified as the most important precondition for resilience of disaster-prone areas [47]. Vulnerability is the set of conditions and processes resulting from physical, social, economic, and environmental factors, which increase the susceptibility of a community to the impact of hazards. To measure the vulnerability in the selected study area, 25 indicators were employed (Table 2). For positive relationship, vulnerability increases with the presence of indicator whereas for negative relationship, vulnerability decreases with increasing value of indicator.

Table 2. Different indicators of vulnerability assessment.

Sl. No.	Indicators	Description	Relationship with Vulnerability	Reference
1	Population density	Vulnerability is high in densely populated areas as many people live there.	Positive	[7]
2	Population growth rate	High population growth rate leads to high vulnerability of the society.	Positive	[25]
3	Female population	Women are more vulnerable due to their family responsibilities and low salary.	Positive	[48]
4	Child population (0–6 Years)	Children are always dependent on another person.	Positive	[49]
5	Rural population	Rural people suffer poor communication and medical facilities due to the remoteness from the urban area.	Positive	[25]

Table 2. *Cont.*

Sl. No.	Indicators	Description	Relationship with Vulnerability	Reference
6	Literacy	Education and employment are inextricably linked. Higher education leads to better job opportunities.	Negative	[50]
7	Female literacy	Female literacy increases the chance of having a job for women.	Negative	[25]
8	Primary school density	Higher primary school density enhances chance of education for every child.	Negative	[9]
9	Employment rate	Employed people have good economic condition which means good standard of living.	Negative	[51]
10	Households with bad house condition	Bad condition of house increases the probability of damage from flood.	Positive	[9]
11	Households without electricity	To use modern technologies, electricity is absolutely needed.	Positive	[32]
12	Households without sanitation	Sanitation facility can reduce health related problems.	Positive	[32]
13	Households without sewage	Sewage system helps to get water out. Having no sewage system in house increases the impact of flood.	Positive	[32]
14	Households having source of safe drinking water	Safe drinking water is essential for health, as it prevents exposure to unappealing pollutants, bacteria, viruses, and parasites.	Negative	[52]
15	Households having kitchen	Households with a kitchen are hygienic.	Negative	[9]
16	Households having banking service	Banking facility supports economic condition.	Negative	[53]
17	Cultivator	Effect of flood has a huge impact on agriculture. Damage of crops is directly related to cultivator.	Positive	[25]
18	Agricultural labor	Agricultural laborers have no work during the flood period.	Positive	[25]
19	Area covered by irrigation (ha)	More area covered by irrigation means higher adaptive capacity.	Negative	[25]
20	Seed storage/10 sq. km	If agricultural productions are damaged by flood, seed stores are very important for re-planting.	Negative	Proposed in this research work
21	Average number of co-operative societies/0.1 million population	The co-operative society helps in product marketing, storage facilities, processing, transport, and availing intensive cultivation by modern techniques.	Negative	[25]
22	% of people having membership in co-operative societies	Co-operative societies grant agricultural loan to the members.	Negative	[25]
23	Number of bank/0.1 million population	Number of bank/0.1 million population facilitates economic infrastructure of the region.	Negative	[25]
24	Road density	Roads are important for rescue purpose during any type of hazard.	Negative	[9]
25	Permanent flood shelter/10 sq. km	Flood shelter is extremely important before and after disaster. It is a temporary home for the flood-affected people. These shelters are used to manage relief and rehabilitation activities in an organized way.	Negative	[52]

There are many methods for data normalization like z score, min-max rescaling transformation, maximum value transformation, etc. [32]. The normalization of vulnerability indicators is carried out through the min-max normalization method [54–60]. In this method, data are transformed to a specific range (0–1), which confirms that all the features have the exact same scale. Min-max rescaling transformation is determined by the following Equations (2) and (3) [59,61].

For positive relationship,

$$x = \frac{Xi - Min}{(Max - Min)} \quad (2)$$

For negative relationship,

$$x = \frac{Max - Xi}{(Max - Min)} \quad (3)$$

where,

x = Normalized value of indicator,
Max = Highest value of the indicator within all blocks,
Xi = Actual value of the indicator,
Min = Lowest value of the indicator within all blocks,

To reduce the dimension of indicators, the principal component analysis (PCA) technique was employed. PCA is considered as a better empirical method than other alternative methods of reducing dimensionality in the data, like correspondence analysis, multivariate regression, or factor analysis [62]. The criteria to retain all the factors were selected based on eigenvalues greater than 1 (Kaiser Criterion). Because if the eigenvalue is less than 1.0, the factor explains less information than a single item would have explained. Horn [63], Crawford [64], Velicer [65] also suggested some rules to retain the factors. However, Kaiser's rule is easy to calculate and it is available in many statistical packages. The varimax rotation method was used in PCA. The software Statistical Package for the Social Sciences (SPSS) version 26 was used to calculate the PCA.

After analysis, the vulnerability score was obtained by summing up all the factors, as described in Equation (4) [66].

$$\text{Vulnerability score} = Fac1 + Fac2 + Fac3 + Fac4 + Fac5 + Fac6 + Fac7 \quad (4)$$

Vulnerable regions were also classified into five categories (very low, low, medium, high, and very high), adopted from Gautam [67] and Aksha et al. [66], and weighted value was 1, 2, 3, 4, and 5 respectively (Table 3). Furthermore, de Mello Rezende [68] averaged out all the standardized (method min-max) scores for vulnerability index calculation and classified them into five different levels. Here, vulnerability index was classified through standard deviation calculation of the data.

Table 3. Vulnerability index.

Standard Deviation	Vulnerability Classes	Vulnerability Index
<−1.5	Very low	1
−1.5–−0.50	Low	2
−0.50–0.50	Medium	3
0.50–1.5	High	4
>1.5	Very high	5

2.3.3. Flood Risk Assessment

The flood risk assessment was calculated through a flood risk index by multiplying the indexes obtained for the hazard and the vulnerability. Phongsapan et al. [69] calculated flood risk index by the normalization of the values and categorized low (<5%), moderate (5–10%), and high (>10%) zone. Buta et al. [70] analyzed flood risk index (FRI) by multiplying the flood hazard index (FHI) by the flood vulnerability index (FVI) and classifying it into four categories. In this study, the risk index was classified into five different classes for the detailed explanation of flood risk zones.

Flood risk index was categorized as very low (1–2), low (3–4), medium (5–9), high (10–15), and very high (16–25), as displayed in Table 4. Flood hazard map, vulnerability map, and risk map were created by using ArcGIS software (version 10.2).

Table 4. Flood risk index.

Vulnerability Index	Hazard Index				
	Very Low (1)	**Low (2)**	**Medium (3)**	**High (4)**	**Very High (5)**
Very Low (1)	VL 1 × 1 = 1	VL 1 × 2 = 2	L 1 × 3 = 3	L 1 × 4 = 4	M 1 × 5 = 5
Low (2)	VL 2 × 1 = 2	L 2 × 2 = 4	M 2 × 3 = 6	M 2 × 4 = 8	H 2 × 5 = 10
Medium (3)	L 3 × 1 = 3	M 3 × 2 = 6	M 3 × 3 = 9	H 3 × 4 = 12	H 3 × 5 = 15
High (4)	L 4 × 1 = 4	M 4 × 2 = 8	H 4 × 3 = 12	H 4 × 4 = 16	VH 4 × 5 = 20
Very High (5)	M 5 × 1 = 5	H 5 × 2 = 10	H 5 × 3 = 15	VH 5 × 4 = 20	VH 5 × 5 = 25

3. Results and Discussion

3.1. Flood Hazard Scenario and Its Spatial Variation

The flood hazard map (Figure 5) shows the areas susceptible to floods in the Purba Medinipur district. In the present study, this was determined based on the frequency information of floods. The flood hazard map indicates that the highly flood prone area is in the northern and western parts of the district. These parts of the district are characterized as being gently sloping (0–5 degree) and flat, mostly composed of alluvial soil at the surface. The presence of a high amount of clay particle (60%) makes this soil less permeable. Besides the convergence of rivers, this region is vulnerable to water logging during monsoon season owing to the presence of alluvial soil.

Panskura, Moyna, and Patashpur-I blocks are very high flood prone and have experienced more than eleven floods from 2002 to 2019. Panskura block is mainly flooded by the New Kasai (also known as New Cossye) river [30] and Patashpur-I is usually flooded by the Keleghai river. More than 70% of the soil in the Patashpur-I block is clay-like in texture [71] Moyna block is surrounded by rivers and a canal on three sides. The Kasai river (also known as the New Cossye river) flows in the east; the Chandia river flows in the west; the Chandia and Keleghai rivers flow in the south; and the Baksi canal is on the northern part of the block [72] and forms a basin-like topography. The whole Moyna block is situated in a low land [73]. All these factors make the Moyna block extremely vulnerable to flood and waterlogging.

The New Cossye and Kaliaghai rivers are mainly responsible for the floods in the Purba Medinipur district. The reoccurrence interval of high magnitude flood events in the Kaliaghai river is 1 in 2.1 years [74]. From 2002 to 2019, the New Cossye river crossed the danger level thirteen times (Figure 6). The water level of Kaliaghai also crossed the danger level eleven times (Figure 7) within the study period (2002–2019). The Rupnarayan and Rasulpur rivers are also responsible for floods in the district.

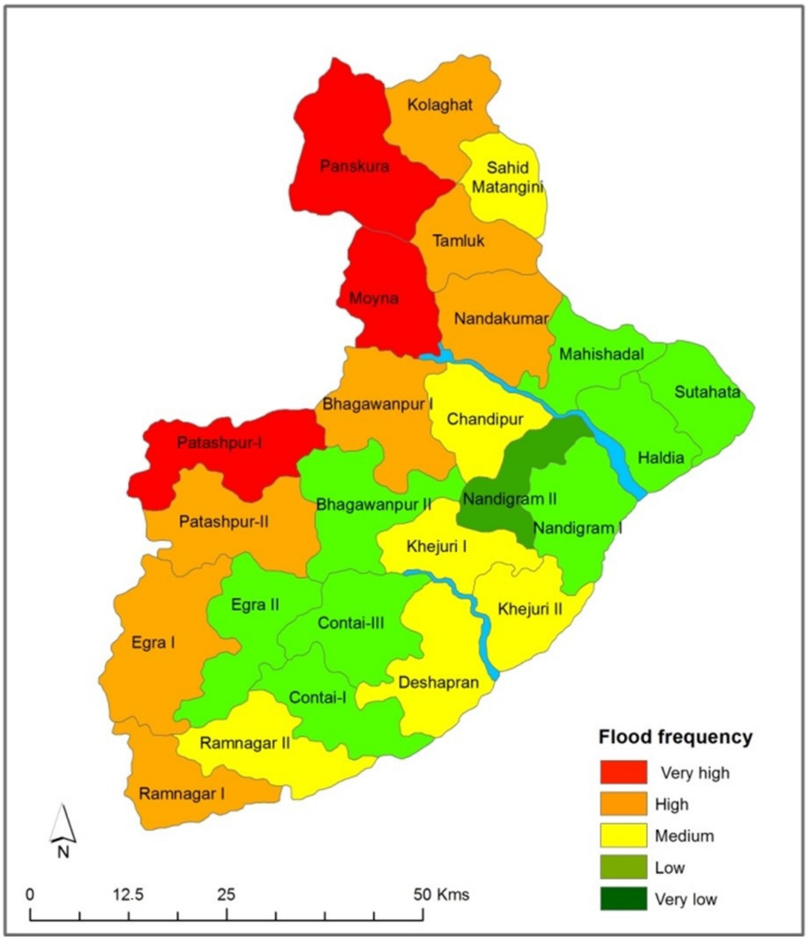

Figure 5. Flood frequency map of Purba Medinipur district (2002–2019).

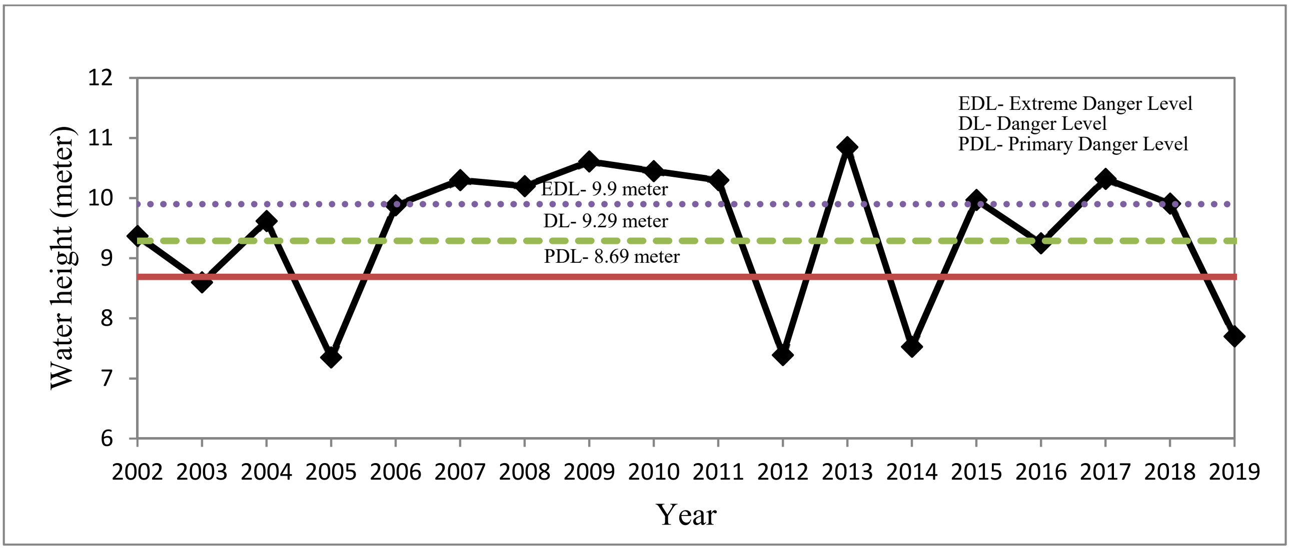

Figure 6. Highest gauge height in New Cossye river at Panskura rain gauge station (2002–2019).

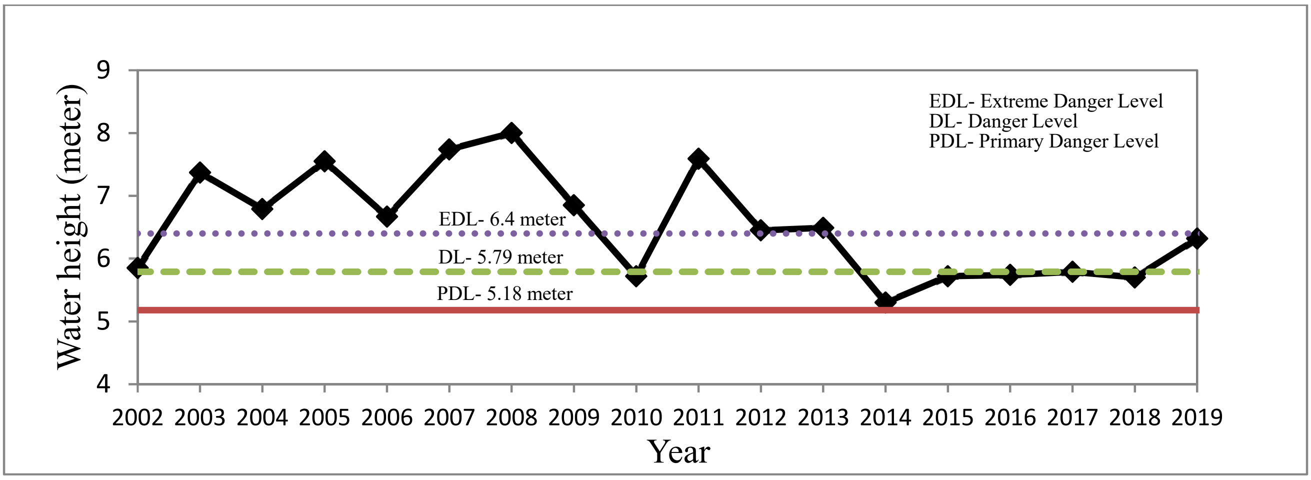

Figure 7. Highest gauge height in Kaliaghai river at Amgachia rain gauge station (2002–2019).

During the study period, the Tamluk, Kolaghat, Nandakumar, Patashpur-II, Bhagawanpur-I, Egra-I, and Ramnagar-I blocks suffered ten to eleven floods that were grouped as high category. Only the Nandigram-II (five floods from 2002 to 2019) block was in the very low flood category, being in the lap of the Bay of Bengal.

3.2. Understanding the Vulnerability Scenario and Its Spatial Variation

Another component of risk assessment is vulnerability analysis. Flood maps alone are not sufficient to measure the risks to people, property, infrastructure, and services [75]. The damage of floods also depends on the vulnerable condition of the region. Seven factors (Table 5) have been determined from selected indicators using PCA and contributed to understanding the vulnerability in the Purba Medinipur district. Seven factors explained 83.84% of the total cumulative variance. The first three factors have more than half of the variance. Kaiser's [76] rules explained that an appropriate threshold for component extraction includes those factors having an eigenvalue greater than 1.00. Following this rule, only the first seven factors were retained for final analysis.

Block wise scores of seven factors were summed up to obtain the total vulnerability score followed by Cutter et al. [77], Aksha et al. [66], and Mavhura et al. [20]. Total vulnerability scores were classified into five categories. Table 6 represents the total vulnerability score of each and every block of the district. The Khejuri-II block has the highest vulnerability and the Tamluk block has the lowest vulnerability. A high vulnerability score indicates low economic status and underdeveloped infrastructure of the society.

Table 5. Total variance explained.

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	7.115	28.460	28.460	7.115	28.460	28.460	4.780	19.120	19.120
2	3.744	14.975	43.435	3.744	14.975	43.435	3.705	14.818	33.938
3	3.535	14.140	57.574	3.535	14.140	57.574	3.346	13.384	47.322
4	2.057	8.229	65.804	2.057	8.229	65.804	2.730	10.919	58.241
5	1.794	7.178	72.982	1.794	7.178	72.982	2.318	9.271	67.512
6	1.477	5.906	78.888	1.477	5.906	78.888	2.248	8.993	76.504
7	1.238	4.952	83.840	1.238	4.952	83.840	1.834	7.335	83.840
8	0.991	3.964	87.803						
9	0.634	2.536	90.339						
10	0.500	1.998	92.337						
11	0.424	1.696	94.034						
12	0.382	1.526	95.560						
13	0.307	1.229	96.788						
14	0.245	0.980	97.769						
15	0.143	0.571	98.339						
16	0.131	0.523	98.863						
17	0.110	0.439	99.302						
18	0.064	0.255	99.557						
19	0.043	0.171	99.727						
20	0.035	0.142	99.869						
21	0.024	0.097	99.966						
22	0.007	0.027	99.994						
23	0.001	0.004	99.998						
24	0.001	0.002	100.000						
25	-3.523×10^{-17}	-1.409×10^{-16}	100.000						

Extraction Method: Principal Component Analysis.

Table 6. Vulnerability score of seven factors for twenty-five blocks of Purba Medinipur district.

Blocks	Fac1	Fac2	Fac3	Fac4	Fac5	Fac6	Fac7	Total Vulnerability Score
Khejuri-II	1.035	1.191	1.973	1.224	0.164	0.948	0.011	6.546
Nandigram-I	0.667	1.821	1.124	0.147	1.440	−0.512	−0.006	4.681
Moyna	−1.213	−1.489	−0.212	0.364	1.424	1.257	1.934	2.065
Chandipur	−0.527	0.598	−0.172	0.218	1.173	0.701	0.058	2.048
Ramnagar-I	0.428	0.744	0.064	1.994	−2.853	0.459	0.687	1.523
Sutahata	−0.748	1.325	0.199	−0.293	0.089	−0.725	1.567	1.415
Nandigram-II	−0.052	1.461	−0.275	0.728	0.273	0.487	−1.216	1.407
Potashpur-II	1.488	−0.780	0.354	−0.276	0.516	0.096	−0.007	1.391
Khejuri-I	0.324	0.541	−0.887	1.003	1.304	−0.777	−0.212	1.296
Deshapran	1.068	0.167	−0.487	0.118	0.311	−0.542	0.653	1.288
Panskura	−0.565	−0.978	1.670	−0.204	−0.618	0.987	0.507	0.798
Bhagawanpur-II	0.087	−0.438	−2.093	1.099	0.464	0.250	0.810	0.178
Haldia	−0.217	1.551	0.044	−3.093	−0.674	1.684	0.518	−0.189
Nandakumar	−0.865	−0.268	0.805	−0.020	0.567	0.107	−0.565	−0.238
Egra-I	2.015	−1.549	1.631	−0.961	−0.098	−1.276	−0.266	−0.504
Potashpur-I	0.199	−1.729	−0.309	0.048	−0.833	1.880	0.104	−0.639
Ramnagar-II	1.054	−0.183	−1.021	0.125	−1.078	−0.128	0.373	−0.858
Egra-II	1.072	−1.087	−0.318	−0.368	0.901	−1.155	0.046	−0.909
Bhagawanpur-I	−0.593	−0.421	−0.429	−0.431	1.217	1.261	−1.708	−1.103
Mahishadal	−0.530	0.282	−0.126	0.058	−0.451	−0.384	−0.064	−1.215
Sahid Matangini	−1.752	−0.261	−0.060	0.607	−0.157	−1.627	0.500	−2.750
Kolaghat	−1.212	−0.543	0.919	−0.023	−0.962	−1.260	0.185	−2.896
Contai-III	0.433	−0.138	−1.161	0.288	−0.800	0.430	−2.603	−3.552
Contai-I	0.301	0.557	−1.763	−1.986	−0.743	−1.058	0.534	−4.158
Tamluk	−1.898	−0.374	0.529	−0.364	−0.577	−1.102	−1.842	−5.628

The goal of vulnerability analysis is to understand how the components of vulnerability are impacted by a flood. The result of this attempt focuses on the weaknesses of the society that cause threats in livelihood. According to the result shown in Figure 8, the Khejuri-II and Nandigram-I blocks are very vulnerable. High population growth rate, a large share of child and rural population, less number of agricultural society and membership, low number of banks/0.1 million population, etc. are the main driving factors of high vulnerability at Khejuri-II and Nandigram-I. Most of the blocks of the district appear under the medium vulnerable category. Owing to the availability of better facilities and amenities, municipality bearing blocks, i.e., Tamluk and Contai-I, are categorized in the very low vulnerable zone. These two blocks have a low population growth rate, less of the share of the child population, a high concentration of female literacy, a lower number of cultivators, and less agricultural labor.

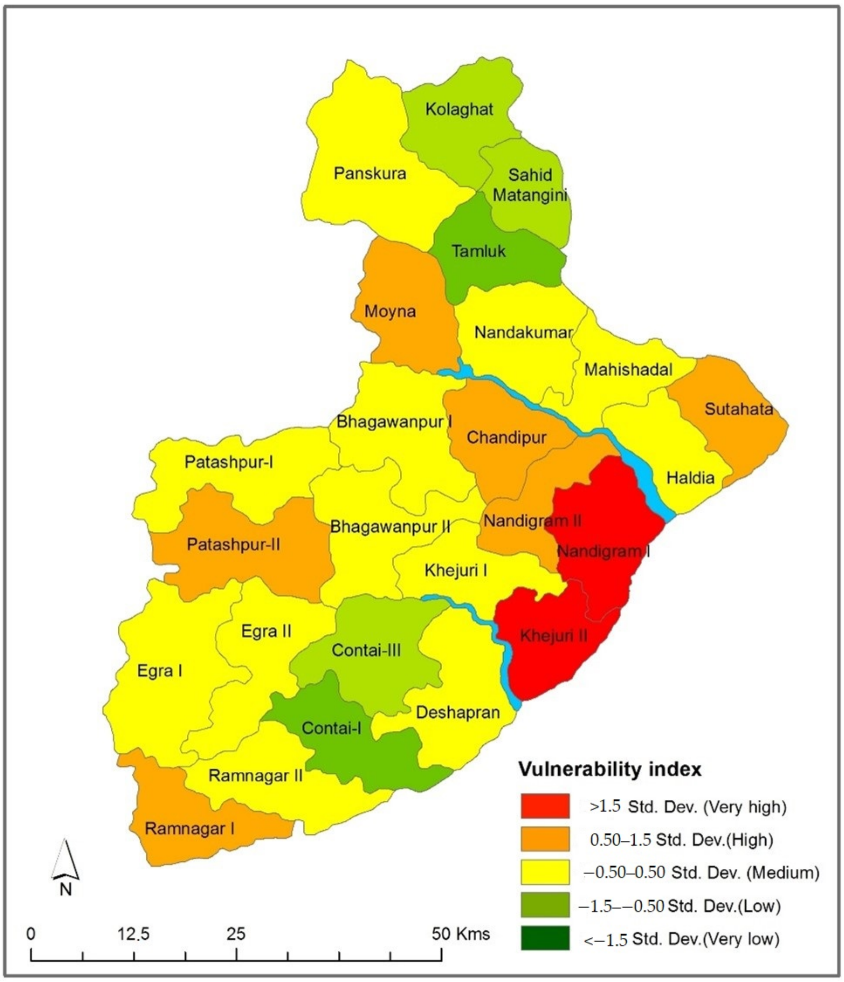

Figure 8. Vulnerability map of Purba Medinipur district.

3.3. Flood Risk Analysis of the Study Area

Figure 9 represents the flood risk map, based on Equation (1) overlayed with the flood hazard map and vulnerability condition. The zone number of flood hazard and the zone number of vulnerability were multiplied (Table 4) and then five risk classes were identified to be categorized into five different zones. Furthermore, 12% of blocks lie in the very high risk zone, 32% of blocks are in the high risk zone, 40% of blocks are in the medium risk zone, 12% of blocks stay in the low risk zone, and only 4% of blocks lie in the very low risk zone.

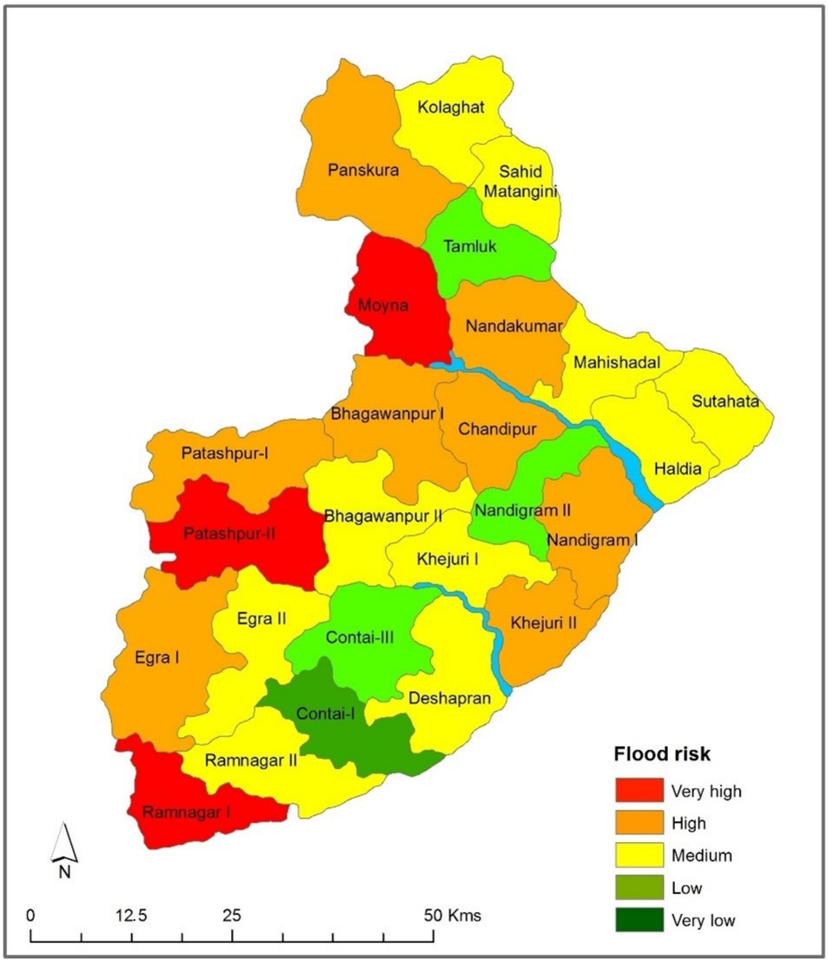

Figure 9. Flood risk map of Purba Medinipur district.

The map indicates that the northern and western part of the district are more vulnerable to floods. Moyna and Patashpur-II, the two most vulnerable, risky blocks are situated in the western part. In addition, most of the high risk categorized vulnerable blocks (Panskura, Nandakumar, Bhagawanpur-I, Chandipur, Patashpur-I, and Egra-I) are located in the northern and western part of the district. Comparatively, the eastern part of the district is less vulnerable. Mainly very low, low, and medium types of flood risk zones are observed in this portion. Only two blocks (Khejuri-II and Nandigram-I) with high risk are located in the eastern part of the district. The map displays that one very high risk block, Ramnagar-I, is clustered in the southern part of the district. Moyna, Patashpur-II, and Ramnagar-I come under the very high risk category as the probability of flood is very high and also the blocks are socio-economically highly vulnerable. Flood risk is highest in the Moyna block of the Purba Medinipur district because it is in the very high flood hazard category and the high vulnerable category. Moyna is affected by flood almost every year. Contai-I is the least risky block within the district. The Contai-I block is low flood prone and very low vulnerable and this means it is relatively safe from flood risk.

The Tamluk and Kolaghat blocks fall under the high flood prone zone. However, as they fall in very low (Tamluk) and low (Kolaghat) vulnerable zones, the risk level is low (Tamluk) and medium (Kolaghat), respectively. On the contrary, Nandigram-II has a high level of vulnerability, but flood hazard probability is very low. So, the Nandigram-II block appears to have a very low level of flood risk.

4. Conclusions

Risk assessment is essential for planning and development initiatives in flood prone areas. In this study, flood risk is represented as combined effort of flood hazard and vulnerability assessment for the tropical monsoon region. Here the risk is not only related to the hazards but also to the understanding of the vulnerability of the community, which indicates the exposure scenario of that society. Moyna appears to be the most risky block in the Purba Medinipur district, depicting the high exposure condition towards the negative impact of floods. On the other hand, due to very low vulnerability, the community of Contai-I can resist hazard effects and can recover very quickly from a hazardous condition. The analysis of flood risk at a micro level of understanding could be done by studying a particular flood prone block like Panskura, or Moyna, or Patashpur-I, etc. Similarly, potential damage evaluation is a part of flood risk assessment. However, unfortunately, geo-hydrological data like depth of flood water in affected regions, number of flooding days, amount of rainfall at local level, etc. are still not available. So, the potential damage is not possible to include in the present work. Highest gauge height data are limited and only recorded in the main channel in a sporadic manner. Machine learning (ML) could be used to create a flood map and to forecast floods. Mosavi et al. [78] and Fu et al. [79] have shown ML for flood prediction. For the vulnerability analysis, unavailability of data is one of the most vital controlling factors which limits the applicability and affects the indicators during the assessment procedure. After the 2011 census (Census of India), no data were available at the block level in the public domain. Emergency response measures like forecasting, evacuation route, etc. also help to mitigate and minimize the damaging effects of floods. However, due to lack of data these types of considerations were not employed in this study. Furthermore, the study could be improved by adding more indicators. Indicators applied by Kuhlicke et al. [51] (duration of evacuation, previous flood experience, household income, tenure), Kablan et al. [80] ((vegetation cover per sub-district, unplanned waste deposits (number), number of people insured (%)), and Jha and Gundimeda, [9] (percentage of disabled population, families below poverty line, percentage of households with access to a location for drinking water, road density) can be included in future studies. The result of vulnerability is highly dependent upon the indicators and so the resulting vulnerable zones may change.

The dredging of riverbeds and the bifurcation of channels in the New Cossye, Kaliaghai, Rupnarayan, and Rasulpur rivers are urgent matters that need immediate attention. Afforestation, soil conservation in the catchment area of the river, and small check dams are also needed. Hazard-related knowledge is also required for local people and evacuation skills for flood rescue are to be practiced regularly. To reduce the vulnerability from floods, the primary requirement is to develop infrastructure to adapt people to the inundation conditions. Another important remedial measure is to enhance economic development. These adaptive measures can help to minimize flood vulnerability and may be useful in the planning ecosystem. By following this research methodology, flood risk maps for other districts in West Bengal can be made. Proper steps are necessary to reduce floods and their vulnerability in high risk regions, and this work could provide an opportunity to develop integrated flood-risk plans for the Purba Medinipur district. Thus, flood risk assessment through flood hazard and vulnerability can provide a useful attempt at natural resource management and it is also essential to improve the livelihood of people at the micro level.

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