Assessment of Flood Vulnerability in Jamuna Floodplain: A Case Study at Jamalpur District, Bangladesh

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Abstract

Flooding is a recurring event, and Bangladesh is particularly vulnerable to it. This study aimed to assess the Jamuna floodplain's community vulnerability. A concise overview of the literature had performed to identify and finalize the indicators of vulnerability. Expert judgments used to weight the selected indicators. Primary data were collected using a pretested questionnaire throughout the field, where 400 households have been interviewed. Using multi-stage sampling techniques, five Upazilas of Jamalpur district, including Dewanganj, Islampur, Madarganj, Melandaha, and Sharishabari, were purposively chosen following extensive flood damage reports. Percentage value was derived using SPSS for each variable collected from the field survey. The variable vulnerability index (VVI) was derived by dividing the weighting value by the field percentage value for each variable. Exposure, sensitivity, and adaptive capacity have been calculated using the variable vulnerability index values. Finally, using a widely recognized established index, the vulnerability was assessed for the study area. The calculated vulnerability scores for Dewanganj, Islampur, Madarganj, Melandaha and Sharishabari are 0.86, 0.84, 0.71, 0.70 and 0.65. According to the survey findings, all the study sites are found highly vulnerable to floods, especially Dewanganj and Islampur Upazilas, due to poor socio-economic conditions, low adaptive capacities, and high exposures. This study recommends resistant materials like brick and concrete in housing construction, sustainable flood-resistant dams and improving their adaptive capacities through socio-economic uplift.

1 Introduction

In modern times, the field of natural hazard and disaster management has advanced. With the advancement of this field, vulnerability assessment study is employed spontaneously and effectively to manage flood disasters. Such studies are considered an efficient flood hazard management tool (Fekete and Brach, 2010). Vulnerability studies are generally categorized by physical, social, and human vulnerability (De León, & Carlos, 2006; Balica et al. 2009). Vulnerability can be assessed by combining several parameters such as adaptive capability, sensitivity, and exposure (Fekete and Brach, 2010; Balica, & Wright, 2010; Adger, 2006; Balica, 2012; Balica et al. 2012). Adaptive capacity is considered as the most important element in many definitions of vulnerability (Scheuer et al. 2011) and described as the ability of a community to cope with environmental threats. Sensitivity refers to the degree to which uncertainty affects a system, whereas exposure refers to the level to which a community is subjected to environmental hassle (Fekete and Brach, 2010; Boshier et al. 2009). Only exposure and coping capacity were used to measure vulnerability in Clark et al. (1998) and Kelman (2003), with coping capacity being further divided into resistance and resilience. While assessing vulnerability, a wide variety of variables are used. That is why flood vulnerability assessment is a comprehensive and intricate process (Fekete and Brach, 2010; Scheuer et al. 2011). Poor people in a community frequently live near a river despite being aware of its devastating flooding nature due to poor socio-economic conditions, making them more vulnerable to flooding (Brouwer et al. 2007). Due to data limitations and the intricate nature of absolute vulnerability measurement, accurate vulnerability measurement using indicators is not possible all the time. That is why some proxy indicators can be used to assess flood vulnerability. Individual characteristics such as age, racial group, gender, income status, housing type, and occupation can be used as proxy indicators for flood vulnerability assessment (Cutter et al. 2013). Flood exposure refers to a risk of direct impact on individuals and/or structures while flooding. (Balica, & Wright, 2010). The total number of components exposed during a flood hazard increases the chances of being harmed. This is known as susceptibility or sensitivity. Susceptibility

is such a parameter of flooding, which includes the community preparedness and awareness level (Balica et al. 2012).

Bangladesh is a riverine country, and it is known as highly vulnerable to flood due to its low-lying topography (Brouwer et al. 2007, Mirza, 2002, 2003, Mirza et al. 2003). Due to the country's particular geographic location and impoverished socio-economic status, it is vulnerable to various natural disasters, but floods pose the greatest threat (Younus, 2020). As a consequence of climate change and sea-level rise, the country is under a massive threat of more frequent and devastating flood events, which might affect the livelihoods of millions of marginal farmers. The government sought more technological and economic assistance from the international community at the World Climate Conference 3 in Geneva in 2009 to help the community develop mechanisms to minimize flood vulnerability. (Younus, 2020). The government has taken several initiatives to reduce flood vulnerability. To minimize the adverse impact and reduce vulnerability, they have taken structural and non-structural flood management measures (Paul, 1995). There has been extensive research on floods in Bangladesh, but vulnerability assessment by selecting indicators has not been done yet. Some researchers (Brammer, 1990, Brouwer et al. 2007, Mirza, 2002, 2003, Mirza et al. 2003, Webster et al. 2010) have conducted individual studies on flood hazard, regional cooperation, and adjustments, but vulnerability assessment and recovery strategy still require much closer scrutiny.

The Jamuna river basin faces the devastating consequences of the historical floods in Bangladesh, including 1988 and 1998 (Brammer, 1990; Brouwer et al. 2007; Mirza, 2003; Webster et al. 2010). During the previous event in 2017, approximately 1200 unions of 183 Upazilas in 31 districts were affected, including a total of 8746 villages, where Jamalpur district (Jamuna River floodplain) suffered the most in various ways (Nirapad, 2019). Floods cannot be prevented, but the number of flood losses in communities can be reduced using a new approach such as vulnerability and resilience assessment (Batika et al. 2013). Approximately 80% of Bangladesh comprises floodplains, which have a very low mean height above sea level (Ahmad et al. 2004). That is why sustainable flood management is badly needed here, which can be done through a vulnerability assessment. Every year, the Jamalpur district is badly flooded; hence, this study aims to assess the district's flood vulnerability.

2 Materials And Methods

2.1 Study area description

Most of the population of Bangladesh lives in flood plains with varying degrees of river flooding every year (Ferdous et al. 2019). Jamuna river floodplain, Bangladesh, was taken as a study area for this study. The Jamuna floodplain covers a vast area, including Gaibandha, Jamalpur and Sirajgonj districts. Jamalpur district is situated in the northern part of Bangladesh, taken as a case study. The district's general area is 2115.12 square kilometres, with 18.16 square kilometres of forest. Between 24°34 and 25°26 north latitudes, and 89°40 and 90°12 east longitudes, the district is located (BBS, 2011). The climate in Jamalpur is warm and temperate. There is significantly less rainfall in the winter than there is in the summer. This climate is classified as Cwa, according to Köppen and Geiger. The annual average temperature in Jamalpur is 26.0°C degrees Celsius. This area receives an average of 1963 millimetres of rainfall every year. This district's average yearly temperature ranges from a maximum of 33.3°C to a minimum of 12°C (BBS, 2011).

Comparatively, Jamalpur district is a warmer district than the others. The prominent rivers in this district include the Jamuna, Brahmaputra, Jhenai, Banar, Jirjira, and Chhatal (BBS, 2011). Nearly every monsoon carries river floods in this area. Five Upazilas, including Dewanganj, Islampur, Madargonj, Melandaha and Sharishabari, are comparatively low areas and are the worst sufferers of annual floods. That's why these five Upazila have been selected for primary data collection. Jamalpur district have a population of 2292674 people with a population density of 1084 people per square kilometre, according to the 2011 census. The literacy rate is 38.4%, and the average household size is 4.06. The economy of Jamalpur district is primarily dependent on agriculture, with 62% of the population dependent on agriculture. Besides, most people live here by fishing. That's why people of this area have to live and depend near the river (BBS, 2011).

2.2 Sampling strategy and data collection

Firstly, Jamalpur district has been selected from the Jamuna floodplain based on previous flood records. Five Upazilas, including Dewanganj, Islampur, Melandaha, Madargonj and Sharishabari, have been chosen as surveyed areas due to extensive flood damage in these areas. The study adopted quantitative techniques to collect primary data from the field. A pretested questionnaire has been prepared, and 400 households have been surveyed at the selected Upazilas of Jamalpur district in 2019. The household that directly affected by the flood considered target units for the household level survey. The Unions were considered clusters in the study, which uses cluster sampling techniques to identify the units of observations. The sample size was calculated using the following formulae based on a 20% indicator percentage (proportion of households affected by flood during the last occurrence in Jamalpur), a 95% confidence interval, 5% precision, and the highest response distribution with an assumed design effect of 1.5.

$$n = \frac{p(1-p)Z^2}{(d)^2} \times Deff$$

Here, P = the indicator percentage (0.2),

Z = the value of normal variants with 95% confidence interval (1.96),

d = the relative error margin,

Deff = the design effect (1.5).

According to the formulae, the minimum sample size is 369; that means the study must include at least 369 households. However, for equal distribution of households within the selected ten clusters, 400 households have been covered.

Out of five selected Upazilas, ten unions have been chosen purposively. From each union, 40 households were surveyed using simple random sampling. As the flood losses are severe in a rural area, that's why rural areas have been surveyed in this study. In addition to the quantitative survey, qualitative surveys such as Focus Group Discussions (FGD), In-depth Interviews (IDI), and Key Informant Interviews (KII) were undertaken to develop a better understanding of the perspectives of various stakeholders. A total of 3 IDI, 2 FGD, and 5 KII have been conducted. The FGD was mainly comprised of flood-affected individuals. Flood victims, government and non-government authorities in charge of disaster management were among the IDI respondents. KII, on the other hand, was performed with the participation of government representatives.

For this research, both primary and secondary data were collected. Some secondary data, including MAP, Literacy rate, Employment status, the Sex ratio, has been collected from the DC office in Jamalpur. Furthermore, rainfall and discharge data were obtained from the BMD, and census data were obtained from the BBS. Several reports, journals, and published papers have been collected as secondary data for this study. A comprehensive literature study determined which factors related to exposure, sensitivity, and adaptive ability should be included in the questionnaire used to collect relevant data from the field. In the absence of a household head, female members such as wives and mothers were the respondents. To cover 400 households was one of the most challenging tasks, and it took almost eight days to collect data from households. One questionnaire took about 30–35 minutes to complete. After sorting out, the data has been analyzed using SPSS and EXCEL software. SPSS version 20 was used to analyze the primary data. The percentages for each indicator were calculated using descriptive statistics. Then the percentage value of the components has been entered into EXCEL for vulnerability analysis.

2.3. Indicators for vulnerability to floods

An index is a quantitative score measurement (Cutter et al. 2013) that can be obtained by combining variables according to certain rules (Sullivan et al. 2005). Nowadays, in disaster studies, there have been widely used indices. The use of indices in disaster studies simplifies the complex data into a single value (Cutter et al. 2013, Cutter et al. 2008). Indicators worked as a tool of decision and policy making in such studies. Indicator selection is most important in vulnerability assessment. Vulnerability is often measured both in quantitative and qualitative ways (Birkmann J, 2007). Absolute measurement of vulnerability using some indicators is not an easy task due to data limitation (Borden et al. 2007, Cutter et al. 2010). That's why some researchers have adopted proxy indicators to assess vulnerability in their studies (Qasim et al. 2017). The vulnerability of this study area was determined through the use of proxy indicators. The variables' results were calculated as percentages to avoid complications associated with using multiple units of measurement. Table 1 contains the identified vulnerability indicators used in this research.

Table 1

Vulnerability assessment indicators and their associated variables Source: (Adopted from Qasim et al. 2017)

Indicator	Variable	Expert weightage	Explanation	Justification & positive or negative impact on vulnerability
Exposure	Past flood experience	98	The percentage of households who have been impacted by floods in the past	Prior flooding experience increases flood vulnerability, +
	Houses constructed near the river	90	The percentage of housing units constructed adjacent to flood-prone rivers.	those who live near river and seashore locations are more susceptible to flooding, +
Sensitivity/ Susceptibility	Poor building material	75	The percentage of housing units made of mud	Flood-prone houses are created from mud, +
	Disabled people	70	The percentage of the population with physical or mental disabilities	Mobility and evacuation are hampered by physical and mental disabilities, +
	Dependents	40	Percentage of dependent population ≥64 years plus percentage of Population ≤15 years	Larger numbers of dependents increase the community's vulnerability to floods, +
	Illiteracy	60	Percentage of illiterate population	A greater illiteracy breeds more vulnerability, +
	Human Loss	50	Percentage of population have lost due to flooding from HH	Loss of a human power from household increase vulnerability, +
	Animal Loss	95	Percentage of cattle's have lost due to flooding from HH	Loss of cattle's from Household increase vulnerability, +
Adaptive Capacity	Information about extreme weather condition	90	Percentage of HH got the flood forecasting timely	Early forecasting reduce vulnerability, -
	HH access to credit facilities	75	Percentage of HH who have life insurance	Credit facilities access decrease the vulnerability, -
	Social networks	25	Percentage of population that have membership in any organization	More social capital means less vulnerability, -
	Education	98	Percentage of population that have high school education	An educated community is less vulnerable, -
	Working age group	90	Percentage of population from age group 15–64	Active people decrease vulnerability, -

Indicator	Variable	Expert weightage	Explanation	Justification & positive or negative impact on vulnerability
	Multiple income source	85	Percentage of population with multiple income sources	People with diverse income streams are less vulnerable to floods, –
	Employment	40	Percentage of population employed	Employed are less vulnerable to floods, –
	Income	80	Percentage of households above poverty line	People above poverty line are less vulnerable to flood hazards, –

2.4. Vulnerability components and their accompanying variables

Three components were used in this study to determine the community vulnerability, including Exposure, Sensitivity/Susceptibility and Adaptive capacity. Exposure had determined in this study based on two variables including, the household's previous flood experience and location near a flood-prone river. The study location is one of the most vulnerable locations to flooding, and the majority of families have experienced flooding in the past. That's why past flood experience was chosen as an essential variable. The variable location represents the number of people currently living near a river prone to flooding (Qasim et al. 2017). Building materials, disability, dependent population and illiteracy were the related variables to assess sensitivity. The building material indicates the percentage of people who had mud houses. The bulk of the respondents from the area had houses made of mud and was vulnerable to floods. A large majority of these types of homes make them more susceptible to floods.

The presence of many disabled and dependents in a community makes it more susceptible to flood hazards (Qasim et al. 2017). So, we also included disability and dependent population for susceptibility measurement. Poverty and illiteracy are also played vital roles that make communities more vulnerable to flood hazards. Therefore, we also included these variables in measuring sensitivity to floods. To measure adaptive capacity, we selected six variables, including working-age group, social networks, education, income, employment and multiple livelihood sources (Qasim et al. 2017). This study's working-age group variable includes the percentage of the population from 15 to 64 years. The people in this age group are active and may decrease vulnerability to floods. They can actively participate in any kinds of physical activities which reduce vulnerability during floods. Social capital can also increase linkages and is considered to help people during disasters. The presence of social networks, therefore, makes communities less vulnerable to floods. Education is an essential variable because educated people must be less prone to disasters (Dufty, 2008). The family's income has an impact on flood vulnerability. With more significant money, people may build houses in safer regions and utilize flood-resistant materials to construct their homes. As a result, the higher a person's income, the less vulnerable they are to flooding. According to the HIES 2016, in Bangladesh, the minimum income of a household given for a rural area is 13442 BDT per month as a standard for poverty measurement. As a result, this definition was used in this study, and people earning less than BDT 13,500 per month were considered poor. Employment is also supposed to affect people's vulnerability to floods. The higher the percentage of individuals employed in a community, the more preventive measures are taken by themselves. Similarly, a community with numerous sources of income is

less vulnerable to flooding. If one source of income is harmed, society may compensate with other sources of income.

2.5 Allocating weights to selected variables and calculating index

Adaptive capacity, sensitivity/susceptibility and exposure were the indicators chosen to assess flood vulnerability in the study area. Each of them consists of more than one related variable. The variable values are collected in percentage to avoid complications and simplify the calculations. Assigning proper weights to the variable is a significant and challenging task in indexing. Weights can be assigned based on their relative importance and locational importance (Mayunga JS, 2007). The weight allocation can be performed by either empirical or subjective methods (Cutter et al. 2010). Due to data limitation, the value weighting was a bit difficult. Therefore, this study uses several literature sources (Qasim et al. 2017, Shah et al. 2018) to choose the variables of vulnerability assessment and used expert judgment in weights allocation. The variable vulnerability index was calculated by dividing the weighted value for each variable by the percentage value collected from the field survey for the same variable. The variable vulnerability index (VVI) was calculated for all the selected variables by a similar process. Low values indicate reduced vulnerability, while high values indicate increased vulnerability for a variable. Then the component vulnerability was calculated by averaging the respective variable vulnerability indices. Following this, we derived the adaptive capacity vulnerability index (AVI), exposure vulnerability index (EVI) and sensibility/susceptibility vulnerability index (SVI). Then the composite vulnerability index (CVI) was calculated using the following formulae (Karmaoui et al. 2016).

Flood Vulnerability Index = (Exposure*Sensitivity)/Adaptive capacity.

Using this formula, CVI was calculated for the five selected Upazilas and compared.

3 Result And Discussion

3.1 Demographic & socio-economic information of the respondents

In Dewanganj, Islampur, Melandaha, Madarganj and Sharishabari there are 258133, 298429, 313182, 263608 and 325320 people. The average household size was 4.06, and the population density in this district was 1084 (BBS, 2011). The sex ratio for Dewanganj, Islampur, Madarganj, Melandaha, and Sharishabari was 96, 99, 98, 97, and 96, respectively, while the average household size was 4.25, 3.98, 4.14, 3.93, and 4.05, respectively. The population density was 1235 per square kilometre for Sharishabari Upazila, which is the maximum for the whole district. The population density for the Dewanganj, Islampur Madarganj and Sharishabari Upazila was 965, 845, 1170 and 1212 per square kilometer.

Table 2
Demographic and socio-economic information of the respondents

Variable	Dewanganj (%)	Islampur (%)	Madarganj (%)	Melandaha (%)	Sharishabari (%)
Educational status	28	35	38	18	43
Illiterate	13	30	17	20	12
Age (Dependents)	37	26	31	29	33
Working aged member	63	74	69	71	67
Social capital	9	16	17	12	5
Disabled population	8	5	3	8	6
Employment status	28	36	46	41	39
Income above poverty line	36	60	29	38	40
Multiple livelihood sources	20	13	25	18	8
Houses build by flood resistant material	3	13	13	20	14
Location of HH near River	86	71	37	45	75

Survey data (Table 2) showed that education status is comparatively higher (43%) at Sharishabari, where the Dewanganj, Islampur, Madarganj and Melandaha have 28%, 35%, 38% and 18%, respectively. The maximum number of inactive populations found at Dewanganj was 37%, and the minimum number found at Islampur Upazila was 26%. The survey found that social capital in Dewanganj, Islampur, Madarganj, Melandaha, and Sharishabari was 9%, 16%, 17%, 12%, and 5%, respectively. Employment status found maximum (46%) for Madarganj Upazila and minimum (28%) for Dewanganj Upazila. Households having more income than the poverty line determined by HIES-2016 were also computed for this study. It is found that 60% of households in Islampur Upazila have incomes above the poverty line. In contrast, only 29% of households in Madarganj Upazila have incomes above the poverty line. Sharishabari Upazila scored comparatively very low (8%) in consideration of multiple livelihood sources. Households using flood-resistant materials during construction are essential to reduce flood vulnerability. The survey reveals that only 3% of households in Dewanganj Upazila used flood-resistant material. About 13% of Islampur and Madarganj Upazila households used flood-resistant material in their house buildings, where Melandaha and Sharishabari found 20% and 14%, respectively. About 86% of households in Dewanganj Upazila live near the river, compared to 71% in Islampur, 37% in Madarganj, 45% in Melandaha, and 75% in Sharishabari Upazila.

3.2 Results of household vulnerability indices

Mean values were used to interpret the results of vulnerability indices. So, 0 was considered a low vulnerability, 0.5 was considered a medium vulnerability and 1 was considered as high vulnerability. All the areas showed high vulnerability. The composite vulnerability index (CVI) for Dewanganj, Islampur, Madarganj, Melandaha, and

Sharishabari were 0.86, 0.84, 0.71, 0.70 and 0.65, respectively (Table 3). For the selected five Upazilas, the overall vulnerability was calculated at 0.80.

3.2.1 Exposure index

The exposure index consists of two variables (past flood experience of households and household location from the river). The exposure indices for Dewanganj, Islampur, Madarganj, Melandaha and Sharishabari were 0.97, 0.89, 0.84, 0.79, and 0.64, respectively. The calculated exposure indices were high because more than 90% of the people in this area had previously experienced flooding. Moreover, most of the population had to live near the river Jamuna and face the devastating consequences of the flood. A Similar study was conducted (Qasim et al. 2017) in three sites in Pakistan. They derived exposure indices of 0.76, 0.73, and 0.72, respectively, for Peshawar, Charsadda, and Nowshera, which is more similar to this study.

Table 3
Vulnerability indices for the sample sites

Indicators and their variables	Dewanganj		Islampur		Madarganj		Melandaha		Sharishabari	
	% value	VVI	% value	VVI	% value	VVI	% value	VVI	% value	VVI
<i>Exposure</i>										
Past flood experience	97	0.99	96	0.98	96	0.98	95	0.97	93	0.95
Location of HH	86	0.95	71	0.79	63	0.7	55	0.61	25	0.28
EVI		0.97		0.89		0.84		0.79		0.61
<i>Sensitivity/Susceptibility</i>										
Poor building material	20	0.27	15	0.20	40	0.53	42	0.56	56	0.75
Disabled people	8	0.11	5	0.07	3	0.04	8	0.11	6	0.09
Dependents	37	0.93	26	0.65	31	0.78	29	0.725	33	0.83
Illiteracy	13	0.22	30	0.5	17	0.28	20	0.33	12	0.2
Human Loss	13	0.26	33	0.66	13	0.26	15	0.3	8	0.16
Animal Loss	53	0.56	93	0.98	91	0.96	55	0.58	80	0.84
SVI		0.39		0.51		0.48		0.43		0.48
<i>Adaptive capacity</i>										
Flood warning	53	0.59	75	0.83	89	0.98	81	0.9	80	0.89
HH access to credit facilities	15	0.2	14	0.19	18	0.24	13	0.17	13	0.17
Social networks	9	0.36	16	0.64	17	0.68	12	0.48	5	0.2
Education	28	0.29	35	0.36	38	0.39	18	0.18	43	0.44
Working age group	63	0.7	74	0.82	69	0.77	71	0.79	67	0.74
HH Income	36	0.45	60	0.75	29	0.36	38	0.48	40	0.5
Multiple income sources	20	0.5	13	0.33	25	0.63	18	0.45	8	0.2
Employment	28	0.43	36	0.42	46	0.54	41	0.48	39	0.46
AVI		0.44		0.54		0.57		0.49		0.45
Composite vulnerability index (CVI)		0.86		0.84		0.71		0.69		0.65

3.2.2 Sensitivity/Susceptibility index

Several variables were used to calculate the sensitivity index, including Poor building materials in construction, disabled people in households, dependent people (people under the age of 15 and people over the age of 64) in

households, illiteracy, human loss and animal loss to previous floods. These variables make a community more susceptible to flood. The sensitivity indices for Dewanganj, Islampur, Madarganj, Melandaha and Sharishabari were 0.39, 0.51, 0.48, 0.43, and 0.48, respectively. According to the index, all of the sites were moderate to extremely sensitive. The fact behind it found a vast number of dependent people, especially under the age of 15. Illiteracy also played a vital role here. Moreover, due to previous floods, most of them had to suffer from animal or property loss, which increases the sensitivity. A study is found (Shah et al. 2018), where they calculated sensitivity indices for Nowshera and Charsadda were 0.56 and 0.55, respectively, which is more similar to this study.

3.2.3 Adaptive capacity index

The variables used to calculate the community's adaptive capacity were timely/earlier flood warning, household access to credit facilities, social networking, working-age group/active people, household income, multiple income sources, and employment. The adaptive capacity for Dewanganj, Islampur, Madarganj, Melandaha and Sharishabari were 0.44, 0.54, 0.57, 0.49 and 0.45, respectively, which indicates the moderately high adaptive capacity. Most of the areas received the earlier flood warning forecasted in several ways. Household credit access facilities, social networking among the people and the districts were found low in this study. Household incomes were found to be moderate, but the working-age group or the active people group was found to be high across all sites. Employment and involvement in multiple livelihood sources could increase the adaptive capacity, which is found moderate also. A similar study was conducted (Shah et al. 2018), where they found similar findings to this study. They calculated the Adaptive capacity index for Nowshera and Charsadda were 0.48 and 0.55, respectively.

3.3 Comparative flood vulnerability analysis within study sites

Household flood vulnerability was compared within the selected five Upazilas. The comparison was made on the basis of selected variables associated with each component. A value near 0 indicates very low vulnerability, a value near 0.5 indicates moderate vulnerability, and a value near 1 indicates very high vulnerability.

The calculated composite vulnerability index (CVI) was 0.86 for Dewanganj, 0.84 for Islampur, 0.71 for Madarganj, 0.70 for Melandaha and 0.65 for the Sharishabari Upazila. Figure 2 shows that the Dewanganj and Islampur Upazilas are incredibly vulnerable to flooding due to their high exposure and sensitivity, while Madarganj and Melandaha show high vulnerability. This study suggests a flood protection dam as Dewanganj and Islampur are very exposed to the river Jamuna. Alternately, authorities should consider increasing the community's adaptive capacity, which will reduce vulnerability. Based on CVI values, a vulnerability map has been prepared for the study area, which is shown in Fig. 2.

4 Conclusion

In this study, variables related to vulnerability and their components were calculated and compared. Calculating their corresponding components, exposure, sensitivity, and adaptive capacity have all been measured. The composite vulnerability indices provide the overall vulnerability scenario of an area. A study reveals that all the selected Upazilas were highly vulnerable to flood. Among the five Upazilas, Dewanganj Upazila is the most vulnerable site than the others in the Jamalpur district. The government should give proper attention to all the selected Upazilas to lower the vulnerability and increase the resilience. To reduce the exposure index value, the

government should build a sustainable dam as most of the population lives near the mighty Jamuna River. Such measure will minimize the suffering and different types of flood losses in the community. People should construct their houses using flood-resistant materials such as brick, concrete etc., which will help to reduce sensitivity. As their income and socio-economic conditions are not so good, both the government and NGOs should help the community to build safer (concrete) houses. Increased adaptive capacity and less flood vulnerability can be achieved by improving education, employment, and participation in different livelihood restoration programs. By taking these measures, the flood vulnerability of a community can be reduced, and loss can be minimized effectively.

5 Declarations

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Figures

Figure 1

Study Area Map

Comparative Analysis

Figure 2

Household vulnerability indices comparison within study sites

Figure 3

Vulnerability map of study area prepared on the basis of index value