Assessment of flood vulnerability in Jamuna floodplain: a case study in Jamalpur district, Bangladesh

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Received: 19 June 2021 / Accepted: 23 September 2022 / Published online: 20 October 2022
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Abstract
Floods are a frequent natural calamity in Bangladesh, where many areas get affected almost every year. An indicator-based vulnerability assessment can help efficiently manage the disaster. Therefore, this study intends to assess the community vulnerability in the Jamuna floodplain, one of the most flood-affected areas, using an indexing method. The index involves many indicators of flood exposure, sensitivity, and adaptive capacity along with their weights, determined based on an extensive literature review. A pretested questionnaire was employed to collect primary data from the study area through 400 household-level interviews. Using multistage sampling techniques, five upazilas from Jamalpur district, i.e., Dewanganj, Islampur, Madarganj, Melandaha, and Sharishabari, were purposefully chosen based on past flood damage reports. The percentage values were derived using SPSS for every variable from the field-level data. The variable vulnerability index (VVI) was computed by dividing the indicator’s weight by its percentage value. Then, exposure, sensitivity, and adaptive capacity indices were calculated using the VVI values. Finally, the composite vulnerability index (CVI) of the five Upazilas has been computed using an established and recognized index formula. The CVI scores for Dewanganj, Islampur, Madarganj, Melandaha, and Sharishabari are 0.86, 0.84, 0.71, 0.70, and 0.65, respectively, which suggest a high overall vulnerability. The scores of the exposure and adaptive capacity indices reveal that Dewanganj and Islampur Upazilas have higher vulnerability than the other three upazilas, especially due to poor socioeconomic conditions, low adaptive capacity, and high exposure. This study recommends some infrastructural development, such as sustainable flood-resistant dams, as the study sites are in a flood-prone zone. Houses should be built using flood-resistant materials like bricks and concrete, which are more resilient than mud. Improvements in education and multiple income sources will help the affected people increase their coping capacity.

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Keywords Flood · Vulnerability · Vulnerability Index · Jamuna floodplain · Bangladesh

1 Introduction

Bangladesh is a low-lying country, which has been identified as one of the most vulnerable countries to climate change due to its strategic geographic location and socioeconomic condition (Hossain et al. 2020), where flooding is a very common annual phenomenon (Reynard et al. 2001). A complex network of 230 rivers, including 57 transboundary rivers, leads the country to be more prone to flooding, among other disasters (Kundzewicz et al. 2014). Riverine floods are unique due to their location, physical characteristics, the abundance of rivers, and monsoon climate, among other flood types (Mondal et al. 2021). Almost 60% of the country has an elevation of less than 6 m above average sea level as a result, regular flooding submerged about 20.5% of the territory each year whereas a catastrophic flood event submerged up to 70% of the country (Singha et al. 2020). According to historical records, five major floods happened in the nineteenth century (from 1842 to 1892). Additionally, fifteen similar floods occurred throughout the twentieth century between 1900 and 1998 (Khalil 1990). Bangladesh was hit by three major floods in 1987, 1988, and 1998, each of which caused a lot of damage and killed a lot of people (Mirza 2003). Some major flooding events with their extents are given in Fig 1.

Climate change, according to experts, will make floods more intense, long, and massive all over the world, particularly in Bangladesh (Hossain et al. 2020).

Flooding is a recurrent and natural event that cannot be prevented, but the damage could be minimized effectively for affected communities using a new approach, such as vulnerability assessment (Batica et al. 2013). Studies related to vulnerability assessment are being employed spontaneously and effectively to manage flood disasters with the consecutive advancement of natural disaster and disaster management techniques. Such studies are considered an efficient flood hazard management tool (Shah et al. 2019, 2020a; Fekete and Brach 2010). Vulnerability studies are generally categorized as physical, social, and human vulnerability (De León and Carlos 2006; Balica et al. 2009). Vulnerability can be assessed by combining several parameters, such as adaptive capability, sensitivity, and exposure.

![Fig. 1 Flooding extent in Bangladesh (Source: BWDB)](https://example.com/floodextent.png)
Adaptive capacity was considered an essential element in many definitions of vulnerability (Scheuer et al. 2011) and was 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; Bosher et al. 2009). While assessing vulnerability, a wide variety of variables are used. That is why flood vulnerability assessment is comprehensive and intricate (Fekete and Brach 2010; Scheuer et al. 2011; Shah et al. 2020b). Due to data limitations and the intricate nature of absolute vulnerability measurement, accurate vulnerability measurement using indicators is not always possible. That is why some proxy indicators can be used to assess flood vulnerability (Qasim et al. 2017; Shah et al. 2018). 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). Several efficient studies were found where they have conducted vulnerability assessments using selective indicators (Shah et al. 2018; Qasim et al. 2017; Solín et al. 2018).

The government of Bangladesh 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; Younus 2014). A vast number of research papers were found on flood management in Bangladesh. Some of them worked on mitigation measures (Mondal et al. 2021), the impact of a flood on livelihoods (Hossain et al. 2020), resilience assessment at community level (Haque et al. 2022) and adaptation to climate change (Younus 2014). Individual studies on flood hazard management, regional cooperation, and adjustments have been conducted by the scholars of relevant fields. But not a single investigation found an indicator-based flood vulnerability assessment at the household level in Bangladesh. The community deals with flooding every year because it is a flood-prone and riverine country; thus, it is unquestionably important to look into the elements that make the community more vulnerable. Findings from such a study could be very important for Bangladesh’s flood management as vulnerability could be reduced by taking some initiatives related to resilience. So far, no other research has been conducted in Bangladesh focusing on indicator-based vulnerability assessment, which makes it a unique assessment in terms of regional perspective.

The Jamuna floodplain experienced the devastating consequences of the historical floods in Bangladesh, including the 1988 and 1998 floods (Brammer 1990; Brouwer et al. 2007; Mirza 2002; Mirza 2003; Mirza et al. 2003; Webster et al. 2010). During the recent event in 2017, approximately 1200 unions of 183 upazilas in 31 districts were affected, including a total of 8746 villages, where Jamalpur district (situated in the Jamuna River floodplain) suffered the most in various ways (Nirapad 2017). Every year, the Jamalpur district experiences severe floods. Hence, this study attempts to assess household-level flood vulnerability in Jamalpur as the adaptive capacity can be increased to minimize the impact. The study addressed several research questions as follows:

1. To what extent are the residents of the community exposed to flooding?
2. How sensitive is the community to a particular flood event?
3. To what extent are they capable of coping with the floods?

Managing flood risk assessment enables sustainable and resilient development. This study will directly help the community who lives in a flood-prone zone, and it will also
help the respective officials, policymakers, and government institutes make improvements to flood preparedness and emergency management.

2 Concept of vulnerability

Numerous disciplinary ideas based on natural or social science conceptual frameworks in disaster risk management and climate change action research support the concept of vulnerability (Field et al. 2012). As a result, there are numerous paradigms for managing vulnerability that are supported by qualitative and quantitative analysis methods (Pelling 2010; Fuchs 2009). In many evaluation methods, vulnerability is defined in terms of the degree of susceptibility or fragility of the communities, systems, or elements that are at risk along with their coping capacity in hazardous situations (Birkmann et al. 2013). In order to manage natural disasters and encourage sustainable social development, the concept of vulnerability has been established in the disciplines of geography, economics, sociology, and the environment. The perception of vulnerability as the potential for a social, economic, and environmental system to be damaged or physically and psychologically harmed (susceptibility concept), as well as its capacity to withstand floods while they are occurring (resistance concept), and its capacity to deal with the negative effects of floods after they have passed (resilience concept), is the minimal common factor. Susceptibility is a notion that defines the passive (negative) side of vulnerability, where susceptibility grows as vulnerability decreases (Solín et al. 2018; Adger et al. 2004). Quantifying diverse vulnerability factors is a common focus of natural science research communities (Kienberger et al. 2009). Physical vulnerability attempts to establish and quantify damage ranges represented by vulnerability curves to aid us in identifying acceptable levels of potential losses (Papathoma-Ko‘hle et al. 2011). Social science approaches usually have a broad focus and look into things like whether there is a chance that an individual home or a community may suffer harm or lose money due to environmental dangers, as well as the external factors that affect social vulnerability (Wisner et al. 2014). According to (Tate 2012; Qasim et al. 2017; Shah et al. 2018), it is not possible to directly measure vulnerability; it can only be expressed through indicators (e.g., proxy variables), which should express the internal predilection or potential of a system’s social, economic, and environmental objects to suffer damage and harm, as well as the ability to cope with the negative consequences of floods. For this assessment, some proxy indicators have been chosen. In order to quantify the exposure, this study examined two variables, including location and past flood experience. The community’s proximity to a flood-prone river and past flood experiences make the community more vulnerable (Qasim et al. 2017; Shah et al. 2018). The sensitivity was calculated using six associated variables, such as building materials, disability, dependent population, illiteracy, human loss, and animal loss. Building construction materials like bricks and concrete are more flood resilient, whereas mud houses increase the vulnerability. Disabled people create hindrances during emergency evacuations and promote vulnerability. Flooding causes both human and animal loss, making a household more vulnerable. The assessment of the adaptive capacity took into account data on extreme weather conditions, household access to credit facilities, social networks, education, working-age group, multiple income sources, employment, and income. Earlier information on extreme weather conditions helped a household as well as a community to take possible protection measures that reduced vulnerability. Household credit access facilities promote their adaptive capacity to flood (Qasim et al. 2017; Shah et al. 2018; Solín et al. 2018). Educated
people were found to be less vulnerable than illiterate ones (Gwimbi 2007; Dufty 2008). Multiple income sources make sure the resistance is strong enough to cope with a particular disastrous event. Income is considered as a vital variable, which ensures an easier come back after a certain shock and helps to increase the adaptive capacity of a household. Expert judgment was used to execute value weighting, in which all of the selected variables were forwarded to an expert in the concerned field, who ranked the variables from 0 to 1 based on their importance. Both the percentage value obtained from the field survey and the given weights to the following variables were used to calculate the variable vulnerability index. Finally, using a recognized formula (Karmaoui et al. 2016), vulnerability has been assessed.

3 Materials and methods

3.1 Research design

The study has been carried out mainly based on primary data. Both quantitative and qualitative methods were applied to collect the necessary data to fulfill the research objectives. However, some secondary data have also been collected from various sources, like BBS, Bangladesh meteorological department, Bangladesh water development board, District commission office, various journals, etc. After rigorous literature review variables were finalized for vulnerability assessment and then using those vulnerabilities, a structured questionnaire were developed to collect quantitative data. In the meantime, the variables needed to be weighted properly. That is why another questionnaire was sent to an expert who ranked the variables using his expertise and based on their locational importance. All the quantitative data was collected using the questionnaire and analyzed using SPSS and Excel software. Individual variable vulnerability index scores were calculated, and composite vulnerability was calculated using those scores, which was the primary goal of this study.

3.2 Study area description

Most of the population of Bangladesh live in flood plains with varying degrees of river flooding every year (Ferdous et al. 2019). The Jamuna river floodplain, Bangladesh, was selected 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. The district’s general area is 2115.12 square kilometers, with 18.16 square kilometers of forest. The district is located between the latitudes of 24° 34 and 25° 26 north and the longitudes of 89° 40 and 90° 12 east (BBS 2011).

The climate in Jamalpur is warm and temperate. There is significantly less rainfall in the winter than in the summer. According to Köppen and Geiger, this climate is classified as Cwa. The annual average temperature in Jamalpur is 26.0 °C. This area receives an average of 1963 mm of rainfall every year, while the average annual temperature ranges from a maximum of 33.3 to a minimum of 12 °C (BBS 2011). Comparatively, Jamalpur district is a warmer district than the others. The prominent rivers in the district include the Jamuna, Brahmaputra, Jhenai, Banar, Jirjira, and Chhatal (BBS 2011). Almost every monsoon carries river floods in this area. Five upazilas, including Dewanganj, Islampur, Madarganj, Melandaha, and Sharishabari, are comparatively low areas and the worst annual flood sufferers (Table 1). That is why we have selected these five upazilas as the study area for
primary data collection. Jamalpur district has a population of 229,674 with a population density of 1084 per square kilometer. 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 is why people in this area have to live by and depend on the river (BBS 2011).

3.3 Sampling strategy and data collection

Firstly, Jamalpur district has been selected from the Jamuna floodplain based on previous flood record data (Nirapad 2017). Five upazilas, including Dewanganj, Islampur, Melandaha, Madarganj, and Sharishabari, have been chosen as survey areas (Fig. 2) due to extensive flood damage in these areas (Nirapad 2017; District Relief and Rehabilitation Office 2019). The study adopted quantitative techniques to collect primary data from the field. A pretested questionnaire has been prepared, and 400 households have been surveyed in the selected upazilas of Jamalpur district in 2019. The households directly affected by the flood were 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. Equation 1 is used to calculate the sample size, which was based on a 20% indicator percentage (proportion of households affected by flood during the most recent occurrence in Jamalpur), a 95% confidence interval, 5% precision, and the highest response distribution with an assumed design effect of 1.5.

\[ n = \frac{p(1-p)Z^2}{(d)^2} \times D_{eff} \]  

(1)

Here, \( p \) = the indicator percentage (0.2),
\( Z \) = the value of normal variants with 95% confidence interval (1.96),
\( d \) = the relative error margin,
\( D_{eff} \) = the design effect (1.5).

According to the formula, the minimum sample size is 369. However, 400 households have been covered for equal distribution within the selected ten clusters.

Out of five selective upazilas, ten unions have been chosen purposively. From each union, 40 households were surveyed using simple random sampling. This study investigated rural areas due to flood severity. 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 a group of flood-affected individuals. The IDI surveyed
flood victims and government and non-government organizations responsible for disaster management, including the district relief and rehabilitation officer in Jamalpur and an official from the Bangladesh Red Crescent Society. On the other hand, KII was conducted with the representatives of the local government where 5 union parishad chairmans were interviewed.

For this research, both primary and secondary data were collected. Some secondary data, including MAP, literacy rate, employment status, and sex ratio, were collected from the office of the Deputy Commissioner in Jamalpur. Furthermore, rainfall and discharge data were obtained from the Bangladesh Meteorological Department (BMD), and census data were obtained from the Bangladesh Bureau of Statistics (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 to collect relevant data from the field. In the absence of a household head, female members such as wives and mothers were interviewed during the interviews. Covering over 400 households was one of the most challenging tasks, and it took almost 8 days to collect data from those households. One questionnaire took about 30–35 min to complete. After sorting out, the data have 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.

3.4 Indicators for vulnerability to floods

An index is a quantitative score measurement (Cutter et al. 2013), which can be obtained by combining variables according to certain rules (Sullivan and Meigh 2005). Nowadays, in disaster studies, indexing methods are widely used. The use of indices in disaster studies simplifies the complex data into a single value (Cutter et al. 2013, 2008). In such studies, indicators were used as a decision-making and policy-making tool. Therefore, indicator selection is the most important step in vulnerability assessment by the indexing method. Vulnerability is often measured quantitatively as well as qualitatively (Birkmann 2007). Absolute measurement of vulnerability using some indicators is not easy due to data limitations (Borden et al. 2007; Cutter et al. 2010). That is why some researchers have adopted proxy indicators to assess vulnerability in their studies (Qasim et al. 2017; Shah et al. 2018). The vulnerability of this study area was determined using proxy indicators. The variables’ results were calculated as percentages to avoid complications associated with using multiple units of measurement. Table 2 contains the identified vulnerability indicators used in this research.

3.5 Vulnerability components and their accompanying variables

Three components were used in this study to determine the community’s vulnerability, including exposure, sensitivity/susceptibility, and adaptive capacity. Exposure was determined in this study based on two variables, including the household’s previous flood experience and its location near a flood-prone river. The location of the study area is one of the most vulnerable locations to flooding, and most of the families have previous flood experience. That is why past flood experience was chosen as an essential variable. The variable ‘location’ represents the number of households situated near a river prone to flooding (Qasim et al. 2017; Shah et al. 2018). Sensitivity was determined using variables such as
| Component                  | Variable/indicator       | Expert weight | Explanation                                                                 | Justification and 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<sup>a</sup> |
|                            | 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<sup>a</sup> |
| Sensitivity/susceptibility | Poor building material   | 75            | The percentage of housing units made of mud                                 | Flood-prone houses are created from mud<sup>a</sup>               |
|                            | Disabled people          | 70            | The percentage of the population with physical or mental disabilities       | Mobility and evacuation are hampered by physical and mental disabilities<sup>a</sup> |
|                            | 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<sup>a</sup> |
|                            | Illiteracy               | 60            | Percentage of illiterate population                                         | A greater illiteracy breeds more vulnerability<sup>a</sup>         |
|                            | Human loss               | 50            | Percentage of population have lost due to flooding from HH                  | Loss of a human power from household increase vulnerability<sup>b</sup> |
|                            | Animal loss              | 95            | Percentage of cattle’s have lost due to flooding from HH                    | Loss of cattle’s from household increase vulnerability<sup>a</sup> |
| Adaptive capacity          | Information about extreme weather condition | 90           | Percentage of HH got the flood forecasting timely                           | Early forecasting reduce vulnerability<sup>b</sup>                |
|                            | HH access to credit facilities | 75           | Percentage of HH who have life insurance                                    | Credit facilities access decrease the vulnerability<sup>b</sup>    |
Table 2 (continued)

| Component          | Variable/indicator           | Expert weight-age | Explanation                                                                 | Justification and positive or negative impact on vulnerability |
|--------------------|------------------------------|-------------------|----------------------------------------------------------------------------|------------------------------------------------------------------|
| Social networks    | Percentage of population that have membership in any organization | 25                | More social capital means less vulnerability$^b$                             |                                                                  |
| Education          | Percentage of population that have high school education           | 98                | An educated community is less vulnerable$^b$                                |                                                                  |
| Working-age group  | Percentage of population from age group 15–64                     | 90                | Active people decrease vulnerability$^b$                                   |                                                                  |
| Multiple income source | Percentage of population with multiple income sources               | 85                | People with diverse income streams are less vulnerable to floods$^b$       |                                                                  |
| Employment         | Percentage of population employed                                   | 40                | Employed are less vulnerable to floods$^b$                                 |                                                                  |
| Income             | Percentage of households above poverty line                        | 80                | People above poverty line are less vulnerable to flood hazards$^b$         |                                                                  |

$^a$ indicates a positive impact (increase vulnerability), while $^b$ indicates a negative impact (reduce vulnerability) on flood vulnerability assessment.
building materials, disability, dependent population, and illiteracy. The ‘building materials’ indicator indicates the percentage of households with a mud-built house. The majority of the respondents from the area had houses made of mud and were vulnerable to floods, making them more susceptible to floods.

The presence of disabled and dependent people in a community makes it more susceptible to flood hazards (Qasim et al. 2017; Shah et al. 2018). So, we also included disability and the number of dependent people as indicators for susceptibility assessment. Besides, poverty and illiteracy also play a vital role in making communities more vulnerable to flood hazards. Therefore, we also included these variables in measuring sensitivity to flooding. 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; Shah et al. 2018). This study’s working-age group variable includes the percentage of the population from 15 to 64 years of age. People in this age group are active and may reduce their vulnerability to floods through participating in various physical activities that reduce vulnerability during floods. Social capital can also increase linkages and is considered to help people during disasters. Therefore, the presence of social networks makes communities less vulnerable to floods. Education is an essential variable because educated people must be less prone to disasters due to their better understanding and decision-making capacity (Dufty, 2008). Household income has an impact on flood vulnerability. With significant amounts of 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 household income expenditure survey (BBS 2017), in Bangladesh, the minimum income of a household given for a rural area is 13,442 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 can be taken by themselves. Similarly, a household with multiple sources of income is less vulnerable to flooding. If one source of income is harmed, it can survive with other sources of income.

3.6 Allocating weights to selected variables and calculating index

Adaptive capacity, sensitivity/susceptibility, and exposure were the main components used to assess flood vulnerability in the study area. Each of them consists of more than one related variable. The variable values are expressed in percentages to avoid complications and simplify the calculations. Assigning proper weights to the variables is a significant and challenging task in indexing. Weights can be assigned based on their relative and locational importance (Mayunga, 2007). Weight allocation can be done by either empirical or subjective methods (Cutter et al. 2010). Due to data limitations, the value weighting was a challenging task in this study. A questionnaire had been prepared using the selective variables and sent to an expert who had conducted several similar studies. Then, he ranked the variables using his expertise and locational importance as well. Rather, this study also considered the suggested weights for the variables collected from several literature sources (Qasim et al. 2017; Shah et al. 2018). The variable vulnerability index (VVI) was calculated by dividing the weighted value for each variable by the percentage value collected from the field survey for the same variable. The same process was followed to calculate the VVI for all the selected variables. A low VVI value indicates 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 estimated the adaptive capacity vulnerability index (AVI), the exposure vulnerability index (EVI), and the sensibility/susceptibility vulnerability index (SVI). From these component vulnerability index scores, the composite vulnerability index (CVI) is calculated using the formula mentioned in Eq. 2 (Karmaoui et al. 2016) for the five selected upazilas.

\[ \text{CVI} = \frac{(\text{Exposure} \times \text{Sensitivity})}{\text{Adaptive capacity}} \]  

(2)

4 Result and discussion

4.1 Demographic and socioeconomic information of the respondents

In Dewanganj, Islampur, Melandaha, Madarganj, and Sharishabari, the population sizes are 258,133, 298,429, 313,182, 263,608, and 325,320, respectively. The average household size was 4.06, and the population density in this district was 1084 per square kilometer (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 kilometer for Sharishabari Upazila, the maximum for the whole district. The population density for the Dewanganj, Islampur, Madarganj, and Sharishabari Upazilas was 965, 845, 1170, and 1212 per square kilometer, respectively. Survey data (Table 3) show that education status is comparatively higher (43%) at Sharishabari, where Dewanganj, Islampur, Madarganj, and Melandaha have 28%, 35%, 38%, and 18% literacy rates, respectively. The maximum number of inactive people is found in Dewanganj (37%), and the minimum number is found in Islampur Upazila (26%). The survey found that social capital in Dewanganj,

| 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              |
Islampur, Madarganj, Melandaha, and Sharishabari is 9%, 16%, 17%, 12%, and 5%, respectively. The employment rate was found to be highest (46%) in Madarganj Upazila and lowest (28%) in Dewanganj Upazila. Households having more income than the poverty line, determined by (BBS 2017), have been computed for this study. It is found that 60% of households in Islampur Upazila have an income above the poverty line. In contrast, only 29% of households in Madarganj Upazila have an income above the poverty line. Sharishabari Upazila scored comparatively low (8%) considering multiple livelihood sources. It is essential to build houses using flood-resistant materials to reduce their vulnerability. The survey reveals that only 3% of households in Dewanganj Upazila used flood-resistant material. About 13% of households in Islampur and Madarganj Upazila used flood-resistant material in their house buildings, whereas Melandaha and Sharishabari account for 20% and 14% of this variable, respectively. About 86% of households in Dewanganj Upazila are situated near the river, compared to 71% in Islampur, 37% in Madarganj, 45% in Melandaha, and 75% in Sharishabari Upazila (Table 3).

To find out the relationship within the variables and visualize the patterns, Pearson’s correlation matrix has been performed (Table 4).

4.2 Scores of household vulnerability index

Vulnerability is interpreted on the basis of VVI values. So, 0 was considered a low vulnerability, 0.5 was considered a medium vulnerability, and 1 was considered a high vulnerability. All the areas show high vulnerability on this scale. The composite vulnerability index (CVI) for Dewanganj, Islampur, Madarganj, Melandaha, and Sharishabari is 0.86, 0.84, 0.71, 0.70, and 0.65, respectively (Table 4). For the selected five Upazilas, the overall vulnerability score was found to be 0.80, which indicates high vulnerability. According to the objective, we will investigate the exposure scenario, the level of sensitivity, and the adaptive capacity of the community. This chapter is going to discuss these sequentially.

4.2.1 Exposure index

The exposure index consists of two variables, i.e., past flood experience of households and the household’s location relative to the river. The exposure indices for Dewanganj, Islampur, Madarganj, Melandaha, and Sharishabari are 0.97, 0.89, 0.84, 0.79, and 0.64, respectively (Table 5). The calculated exposure indices are high because more than 90% of the people in this area have previously experienced flooding. Moreover, most of the population has to live near the river Jamuna and face the devastating consequences of the flood. These findings are in line with previous studies by Qasim et al. (2017), Shah et al. (2018), and others (e.g., Braun and Abheuer 2011; Ludy and Kondolf 2012), which demonstrated that houses near rivers are more prone to flood damage.

4.2.2 Sensitivity/susceptibility index

The terms “sensitivity” or “susceptibility” refer to the degree to which a system is impacted by a variety of internal or external disturbances or sequences of disturbances (Gallopín 2003). 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 due to previous floods. These variables make a community more
Table 4 Pearson’s correlation matrix within the variables

| Educational status | Illiterate | Age (dependent) | Working aged member | Social capital | Disabled population | Employment status | Income above poverty line | Multiple livelihood sources | Houses built by flood resistant material | Location of HH near River |
|--------------------|-----------|----------------|--------------------|---------------|--------------------|-------------------|--------------------------|---------------------------|---------------------------------|------------------------|
| Educational status | 1.00      | 0.16           | 0.12               | -0.16         | -0.69              | 0.20              | 0.08                     | 0.35                      | -0.20                           | 1.00                   |
| Illiterate         | 0.16      | 1.00           | 0.70               | -0.24         | -0.37              | 0.37               | 0.49                     | -0.63                     | -0.71                           | 0.46                   |
| Age (dependent)    | -0.16     | 0.70           | 1.00               | -0.63         | -0.37              | 0.37               | 0.49                     | -0.63                     | -0.71                           | 0.46                   |
| Working aged member| 0.12      | -0.69          | -0.24              | 1.00          | 0.63               | -0.37              | 0.49                     | -0.63                     | -0.71                           | 0.46                   |
| Social capital     | -0.16     | -0.69          | -0.37              | 1.00          | 0.63               | -0.37              | 0.49                     | -0.63                     | -0.71                           | 0.46                   |
| Disabled population| -0.12     | -0.69          | -0.37              | 1.00          | 0.63               | -0.37              | 0.49                     | -0.63                     | -0.71                           | 0.46                   |
| Employment status  | 0.16      | 0.49           | 0.49               | 1.00          | 0.63               | -0.37              | 0.49                     | -0.63                     | -0.71                           | 0.46                   |
| Income above poverty line | 0.49 | 0.49 | 0.49 | 1.00 | 0.63 | -0.37 | 0.49 | -0.63 | -0.71 | 0.46 |
| Multiple livelihood sources | -0.35 | 0.49 | 0.49 | 1.00 | 0.63 | -0.37 | 0.49 | -0.63 | -0.71 | 0.46 |
| Houses built by flood resistant material | -0.19 | -0.19 | -0.19 | -0.19 | 1.00 | 0.63 | -0.37 | 0.49 | -0.63 | -0.71 | 0.46 |
| Location of HH near River | 0.20 | -0.17 | -0.17 | -0.17 | 1.00 | 0.63 | -0.37 | 0.49 | -0.63 | -0.71 | 0.46 |
| Components and their variables | Dewanganj  | Islampur  | Madarganj | Melandaha | Sharishabari |
|--------------------------------|------------|-----------|-----------|-----------|--------------|
|                                | % value    | VVI       | % value   | VVI       | % value      | VVI       |
| **Exposure**                   |            |           |           |           |              |
| Past flood experience          | 97         | .99       | 96        | .98       | 95           | .97       | 93         | .95       |
| Location of HH                 | 86         | .95       | 71        | .79       | 63           | .7        | 55         | .61       |
| EVI                            | .97        | .89       |           |           |              |           |            | .61       |
| **Sensitivity/susceptibility** |            |           |           |           |              |
| Poor building material         | 20         | .27       | 15        | .2        | 40           | .53       | 42         | .56       | 56         | .75       |
| Disabled people                | 8          | .11       | 5         | .07       | 3            | .04       | 8          | .11       | 6          | .09       |
| Dependents                     | 37         | .93       | 26        | .65       | 31           | .78       | 29         | .725      | 33         | .83       |
| Illiteracy                     | 13         | .22       | 30        | .5        | 17           | .28       | 20         | .33       | 12         | .2        |
| Human loss                     | 13         | .26       | 33        | .66       | 13           | .26       | 15         | .3        | 8          | .16       |
| Animal loss                    | 53         | .56       | 93        | .98       | 91           | .96       | 55         | .58       | 80         | .84       |
| SVI                            | .39        | .51       |           |           |              |           |            | .43       | .48       |
| **Adaptive capacity**          |            |           |           |           |              |
| Flood warning                  | 53         | .59       | 75        | .83       | 89           | .98       | 81         | .9        | 80         | .89       |
| HH access to credit facilities | 15         | .2        | 14        | .19       | 18           | .24       | 13         | .17       | 13         | .17       |
| Social networks                | 9          | .36       | 16        | .64       | 17           | .68       | 12         | .48       | 5          | .2        |
| Education                      | 28         | .29       | 35        | .36       | 38           | .39       | 18         | .18       | 43         | .44       |
| Working age group              | 63         | .7        | 74        | .82       | 69           | .77       | 71         | .79       | 67         | .74       |
| HH income                      | 36         | .45       | 60        | .75       | 29           | .36       | 38         | .48       | 40         | .5        |
| Multiple income sources        | 20         | .5        | 13        | .33       | 25           | .63       | 18         | .45       | 8          | .2        |
| Employment                     | 28         | .43       | 36        | .42       | 46           | .54       | 41         | .48       | 39         | .46       |
| AVI                            | .44        | .54       |           |           |              |           |            | .49       | .45       |
| CVI                            | .86        | 0.84      |           |           |              |           |            | 0.69      | 0.65      |
susceptible to flooding. The sensitivity indices for Dewanganj, Islampur, Madarganj, Melandaha, and Sharishabari were 0.39, 0.51, 0.48, 0.43, and 0.48, respectively. All sites are classified as moderately to extremely sensitive according to the index. The fact behind it is that it found many dependent people, especially under the age of 15. Illiteracy also played a vital role here. Moreover, most of them suffered from animal or property loss due to previous floods, which increased the sensitivity. These findings are more similar to another vulnerability study (Piya et al. 2012), which showed the role of education in susceptibility assessment. Our study’s overall sensitivity/susceptibility index results corroborate those of Qasim et al. (2017) and Shah et al. (2018), who also identified that their respective study areas are vulnerable to and prone to flood disasters based on these variables.

4.2.3 Adaptive capacity index

Adaptive capacity is described as an individual household or community’s ability to create and implement various adaptation measures at the household level in response to undesirable consequences caused by unforeseen climate-induced catastrophes such as flooding (Adger and Agnew 2004). The variables used to calculate the community’s adaptive capacity include 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 capacities for Dewanganj, Islampur, Madarganj, Melandaha, and Sharishabari are 0.44, 0.54, 0.57, 0.49, and 0.45, respectively, which indicates a moderate adaptive capacity. Most of the areas that received the earlier flood warning were forecasted in several ways. Household credit access facilities and social networking among the people in the districts are found to be low in this study. Household incomes are found to be moderate, but the working-age group or the active people group is found to be high across all sites. Employment and participation in multiple livelihood sources may enhance adaptive capacity, which is also reported to be moderate. A similar study was conducted (Shah et al. 2018), where they found similar findings to this study. They calculated that the adaptive capacity index for Nowshera and Charsadda was 0.48 and 0.55, respectively. Other similar vulnerability studies (Fuchs and Thaler 2018; Qasim et al. 2015) have also found that social networks, education, working-age, various income sources, and employment contribute significantly to households’ adaptive capability in the context of a flood disaster.

4.3 Comparative flood vulnerability analysis within study sites

Household flood vulnerability was compared within the selected five Upazilas. The comparison was made based on 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 CVI for Dewanganj, Islampur, Madarganj, Melandaha, and Sharishabari is 0.86, 0.84, 0.71, 0.70, and 0.65, respectively. According to Fig. 3, the Dewanganj and Islampur Upazilas are extremely vulnerable to flooding as a result of their high exposure and sensitivity, whereas Madarganj and Melandaha show high vulnerability. This report recommends the construction of a flood protection dam, as Dewanganj and Islampur are very exposed to the Jamuna river. Alternatively, authorities should try to enhance the community’s adaptive capacity, which would lower vulnerability. A vulnerability map of the study areas showing their respective CVI values is given in Fig. 4.
4.4 Findings from the qualitative study

In addition to quantitative surveys, some qualitative surveys were conducted to enrich the research. A total of two focused group discussions were conducted within a group of eight flood-affected individuals. Variables such as location, past flood experience, housing materials, household credit access facilities, multiple income sources, and social networking were included in the checklist of FGD. Almost all of the respondents had experience of a previous devastating flood, whereas a majority of the population lived near the flood-prone river Jamuna. Around half of the population has used mud during household construction, which raises household vulnerability to floods. Very few households were found to have credit access facilities and social networking in the studied area. Multiple income sources also reported low incomes within the groups. All the findings were in line with the quantitative findings.

In addition, 3 in-depth interviews were conducted with the officials from both government and non-government sectors responsible for disaster management. Variables included flood forecasting, hazard reduction programs, humanitarian assistance, human loss, and animal loss due to flooding contributed to preparing the checklist. According to the response, flood forecasting has been conducted, but, in some cases, they face challenges in reaching the forecast in remote locations. Hazard reduction workshops have been organized on a regular basis, but unfortunately, the participation of local people in such programs was not satisfactory. Humanitarian assistance is available from both government and non-government organizations, including food, clothing, medicine, and so on, although the quantitative survey reveals that affected people did not receive enough support after the disaster. Both human and animal loss were found to be significant in the study area and similar findings derived from the quantitative survey.

Moreover, with the presence of a local government representative (5 union parishad chairman), they were interviewed for key informant’s interview where location, past flood experience, employment, humanitarian assistance, and livelihood restoration programs were included in the checklist along with other variables. According to the response, all of them had numerous past flood experiences with devastating consequences. Almost 75% of people lived very near to the Jamuna, which led to the vulnerability, and they urged the building of a sustainable dam as a protection measure. Employment scenario in the study area was not satisfactory which was also covered in the quantitative survey. They need a lot
Fig. 4 Vulnerability map of study areas prepared based on their composite index values
of humanitarian assistance as the losses are unbound. Livelihood restoration programs are not practiced in the studied area, which could reduce flood vulnerability.

5 Discussion

The composite vulnerability index indicates that all study areas are extremely vulnerable to flooding. Table 4 and Fig. 3 illustrate that all locations are highly exposed to the Jamuna river, one of the primary reasons for the high vulnerability. Additionally, Jamalpur districts are flooded annually; as a result, the residents in these areas are particularly exposed to flooding. These two variables significantly increase their exposure, which results in increased vulnerability. According to the sensitivity vulnerability index, all study sites are moderately vulnerable to flooding. A considerable percentage of households built their homes with less resistant materials, increasing their vulnerability. The presence of resistant households ensures resistance and definitely lessens the vulnerability. Residents should focus on materials during construction. The majority of households have dependents and, in certain cases, disabled members, making them more vulnerable to flooding. Education may assist in reducing sensitivity and vulnerability. Education is considered a crucial factor in vulnerability assessment as it can be used from numerous perspectives. For example, an educated person can immediately manage a job and will undoubtedly understand the forecasting of extreme weather conditions. Participation in hazard reduction workshops will be more meaningful with educated people. As animals are a potential source of family income for a rural household, their loss can be significant and such loss due to floods was reported in each study area, which contributes to increased sensitivity. These factors contribute to the community’s vulnerability to flooding.

According to the vulnerability index, all studied areas have a moderate capability for adaptation. Access to credit facilities, social networking, and individuals with multiple income sources was extremely limited across all sites, hindering households’ adaptive capacity. Insurance or credit account access facilities can provide a dramatic comeback to cope with a certain shock and will ensure a prompt adaptive capacity. Multiple income sources always stand against vulnerability to flooding. For example, one had three occupations, including farming, boating, and fishing. If a flood occurs unexpectedly, he may be unable to work in the field, but he can supplement his income by boating and fishing. Sources increase adaptive capacity as well as vulnerability. In other circumstances, households with high exposure and sensitivity to flooding were not rendered more vulnerable due to their strong adaptive capacity. That is why, to improve the overall situation, we must prioritize enhancing the adaptive capacity of flood-affected communities.

6 Conclusion

Bangladesh is a riverine country which is highly vulnerable to flooding due to several natural and man-made factors. This study attempted to measure the overall vulnerability of Jamalpur district, situated near the Jamuna river. To investigate this, we used some indicators to assess exposure, sensitivity/susceptibility, and adaptive capacity at the community level within the study area. It is found that all the areas are highly vulnerable, where Dewanganj and Islampur Upazila scored higher, respectively, than the others. According to the composite vulnerability index, Dewanganj was the most vulnerable upazila in the
district, while Sharishabari was the least vulnerable. However, all the sites are highly vulnerable because of their high exposure and moderate adaptive capacity.

The exposure vulnerability index revealed that all the selected areas are highly exposed to flooding due to the proximity of the Jamuna river and almost everyone had experienced a past flooding event, which led to a high vulnerability. Both the sensitivity and the adaptive capacity were found to be moderate for all the study sites. The number of illiterates in households, dependent people, housing construction materials, and education were mainly responsible for the sensitivity, whereas adaptive capacity was found to be moderate because of less participation in social networking, credit access facilities, and multiple income sources.

First of all, the concerned authorities should build a sustainable flood protection dam on the bank of the river Jamuna. The studied area was one of the most densely populated areas, so it is not possible to relocate all of them. A dam could help them to minimize their exposure to floods. To reduce the sensitivity, people need to make sure to use sustainable materials which are flood-proofed, e.g., brick instead of mud. The main reason for the high sensitivity found was poor building materials. So, to minimize flood vulnerability, inhabitants of the following community need to ensure flood-resistant material in housing. The government can play a significant role in sensitivity minimization by prioritizing education programmes. On the other hand, education can reduce sensitivity and increase vulnerability, so education for all could be a remedy for vulnerability. To increase adaptive capacity, both individuals and governments should ensure that there are a variety of available job opportunities because multiple income sources ensure a steady income and reduce vulnerability. Moreover, community people will need to be massively involved in social networking. They needed to be engaged with numerous networks that could help them eventually to cope with a disastrous situation. Insurance facilities can be an outstanding way to promote adaptive capacity. Government and non-government organizations should organize more and more participatory hazard reduction workshops, and the community should participate in such programmes on a regular basis. Rather, close co-ordination among the government, private organizations, and individuals is badly needed to minimize the flood vulnerability.

Acknowledgements The authors express sincere thanks to Abdulla-Al Kafy and Digonresearch.org for their cordial help in proofreading of the manuscript. The first author received funding from the Ministry of Science and Technology, Government of the People’s Republic of Bangladesh, under the NST fellowship program.

Funding The first author received funding from Ministry of Science and Technology, Government of the People’s Republic of Bangladesh under the NST fellowship program. Grant No. 39.00.0000.012.002.03.18.

Data availability Data will be available on reasonable request.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare no conflict of interest.

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