

# Gender-Specific Flood Vulnerability in Sirajganj Sadar Upazila: An Index-Based Analysis of Multi-Dimensional Impacts

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## ABSTRACT

The interplay between gender and vulnerability is crucial in understanding the impact of climate change-induced flooding. Men and women employ distinct adaptive strategies in response to these events, with significant differences observed between male-headed households (MHHs) and female-headed households (FHHs). This study analyzed the social, infrastructural, economic, and environmental dimensions of vulnerability using a mixed-methods approach, including surveys, interviews, and focus group discussions with 216 households. Findings from the weighted average index (WAI) revealed that FHHs experience higher vulnerability across all dimensions, particularly in social and physical aspects. The disparity in multidimensional vulnerability between MHHs and FHHs is statistically significant, as shown by a t-test ( $F = 3.423$ ,  $p\text{-value} = 0.000$ ). Specifically, 42% of FHHs fall into the very high vulnerability category, compared to just 6% of MHHs. The study identifies sociocultural norms as key contributors to this disparity, influencing households' ability to respond to and recover from flood-related disasters. To mitigate future impacts, the study recommends targeted interventions for FHHs, including improved access to services, capacity-building initiatives, awareness training, livelihood support programs, and greater involvement in disaster preparedness and risk reduction strategies. Addressing these factors is essential for enhancing resilience and reducing vulnerability among FHHs in the face of climate change.

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## 1. INTRODUCTION

Among the most ancient and recognized disasters, floods have persistently posed a threat to humanity throughout history (Ferreira, 2011). Flood events rank among the most prevalent and catastrophic natural disasters on a global scale, impacting billions of individuals and leading to

considerable loss of life and property. From the period of 1995 to 2015, floods adversely affected an estimated 2.3 billion individuals and resulted in approximately 157,000 fatalities worldwide, thereby emphasizing the critical necessity for the implementation of effective disaster response frameworks that integrate risk assessment and strategies for enhancing resilience (Guddo, 2023). Empirical studies suggest that although flood-related fatalities have diminished over time in middle- and high-income nations, there has been an increase in such fatalities in low-income regions, thereby highlighting the existing disparities in vulnerability and the capacity for response (Yu Duan, 2024). Climate change serves to amplify flood risks, with forecasts predicting a 2% rise in global flood risk by the conclusion of the 21st century, particularly in densely populated regions (Dewan et al., 2003).

Bangladesh experiences a recurring and devastating occurrence of flooding, which is exacerbated by its geographical and meteorological characteristics, in comparison to other South Asian countries. On an annual basis, the nation experiences flooding, with approximately 21% of its land being covered by water during the monsoon season. In some cases, this percentage might exceed 60% (Dewan et al., 2003). Historical records indicate that Bangladesh has seen multiple devastating floods, including in 1988 and 1998. The flood in 1998 was exceptionally severe and long-lasting due to high rainfall. The complex river system in Bangladesh exacerbates the susceptibility to floods due to sediment buildup and degradation of riverbeds, which also impede flood management techniques (Gazi and Khalil, 1990). Despite significant investments in flood prevention, the effectiveness of only using structural interventions is debated, highlighting the need for comprehensive plans that include both structural and non-structural elements (Younus 2014).

The Sirajganj district is situated alongside the perilous Jamuna River. The annual monsoon inundation of the Jamuna is substantial, resulting in frequent breaches of its banks, which consequently leads to flooding across numerous upazilas within the Sirajganj district. This region is characterized by persistent inundation, giving it the reputation of being perpetually submerged. However, the susceptibility to flooding is not uniformly distributed throughout the district; certain upazilas exhibit greater vulnerability due to their geographical positioning. Specifically, Chauhali, Kazipur, Sirajganj Sadar, Belkuchi, Ullahpara, and Shahjadpur are the most significantly flood-prone upazilas within the district, as substantial portions of these areas are located within the confines of the Jamuna River. These regions experience both regular and flash floods nearly every year (Bhuyian, 2014).

Hazards transform into disasters when they affect populations that are particularly susceptible. As stated by the Intergovernmental Panel on Climate Change (IPCC), vulnerability denotes the degree to which a system is at risk and unable to cope with the adverse impacts of climate change, which includes severe occurrences such as droughts, floods, and cyclones (IPCC, 2007). Vulnerability also encompasses a range of circumstances that affect the ability of nations, communities, and individuals to avert, alleviate, prepare for, and respond to these hazards (Briceno, 2002; Mehta, 2007). The state of vulnerability results in diverse physical, social, psychosocial, socioeconomic, sociodemographic, and political implications within society (Lindell & Prater, 2003). The level of vulnerability among populations significantly affects each phase of a disaster, from preparedness and coping to recovery. Consequently, recognizing vulnerable groups and comprehending the elements that contribute to their vulnerability is crucial for the formulation of effective disaster risk reduction strategies.

The interrelation between gender dynamics and the multifaceted concept of vulnerability emerges as an increasingly crucial focal point for scholarly inquiry, particularly within the framework of flooding events that are exacerbated by the overarching phenomenon of climate change. A plethora of empirical investigations, including but not limited to the seminal works of Cutter (1993), Denton (2001), and Enarson (2005), have collectively posited that the construct of gender significantly shapes the

mechanisms through which individuals and communities adapt to disasters, with divergent degrees of access to critical capital assets and the selection of distinct livelihood strategies playing a pivotal role in determining the adaptive capacities of both men and women, as elucidated by Naz (2019). Consequently, it becomes evident that a nuanced understanding of vulnerability and adaptive capacity must inherently incorporate a gendered perspective, a notion that has been thoroughly explored in the academic literature, particularly by Dankelman (2002) and Dankelman and Jansen (2012). This intersectional vulnerability may manifest in various forms, ranging from inherent physical differences between genders to the socially constructed roles and relationships that dictate expectations for employment and domestic responsibilities within different cultural contexts. The implications of such vulnerabilities are rendered even more severe in the context of resource-poor developing nations, as noted by Enarson (2005), where systemic inequalities compound the challenges faced by marginalized groups. These entrenched barriers not only exacerbate economic insecurity but also create substantial obstacles to accessing essential resources, thereby limiting opportunities for meaningful community engagement and participation, which, in turn, perpetuates a vicious cycle that further entrenches women's vulnerability in the face of disaster circumstances, as articulated by Dijkhorst and Vonhof (2005).

Individuals of different genders exhibit varying capacities to adapt to the impacts of climate change and disasters, largely shaped by gender norms that influence vulnerability in distinct ways (Bari, 1998; Islam & Hasan, 2023). Gender disparities often heighten women's susceptibility during and after disasters (Gokhale, 2008; Enarson & Chakrabarti, 2009), especially in developing countries where women occupy subordinate social positions and face discriminatory practices in land inheritance and employment (Rayhan, 2010). In countries like Bangladesh, women are commonly engaged in unstable, natural resource-based livelihoods, exacerbated by limited access to land, credit, and financial capital (Davison, 1988; Agrawal, 2003; Naz, 2019). Domestic responsibilities further constrain women's participation in community decision-making, increasing their vulnerability (Fothergill & Squier, 2018; Luna & Hillhorst, 2022). Socioeconomic factors such as age, education, land ownership, and access to training also shape gender-specific adaptive capacities (Dankelman & Jansen, 2012; Deressa et al., 2010; Rehima et al., 2013; Naz et al., 2018). These intersections underscore the importance of integrating gender perspectives into disaster risk reduction strategies. As Smit and Pilifosova (2003) emphasize, gender-sensitive assessments are vital for designing effective interventions. Moreover, the distribution of resources within a community significantly influences resilience and must be considered to reduce gendered vulnerability and promote equitable adaptation outcomes (Davison, 1988; Corbett, 1989).

In recent years, scholarly focus has shifted from hazards to vulnerabilities, emphasizing the social dimensions of disaster risk (Aktar et al., 2021). Vulnerability assessments—covering social, economic, physical, institutional, and livelihood aspects—are essential for anticipating risk and mitigating impacts (Cutter et al., 2003; Wisner et al., 2004; Hahn et al., 2009; López-Martínez et al., 2017). While exposure, sensitivity, and adaptive capacity are widely acknowledged as key components (Weis et al., 2016; Shah et al., 2018), few studies integrate all three in a unified framework. Models such as the IPCC's are commonly used (Balica et al., 2009; Birkmann et al., 2013), but a lack of interdisciplinary integration persists (Schröter et al., 2005; Polsky et al., 2007). Understanding these components holistically is crucial for effective adaptation policies (Jerin et al., 2023), especially as male- and female-headed households experience flood-related vulnerabilities differently, requiring gender-sensitive approaches (Ginige et al., 2014; Ezemonye, 2015).

Although substantial research has been conducted at both national and local levels, there remains a notable lack of studies concentrating on household vulnerability assessments within Sirajganj District, which would facilitate the implementation of measures that are more precise and suited to the requirements of impacted communities. Thus, this study seeks to address these deficiencies by

exploring the social, physical, economic, and environmental dimensions of vulnerability, and by comparing these vulnerabilities between male-headed households (MHHs) and female-headed households (FHHs) in the Mechra, Ratankandi, Baghbati, and Chhangachha Union of the Sirajganj Sadar Upazila. Sirajganj Sadar Upazila, located in Bangladesh, is characterized by a significant degree of flood vulnerability, with the Mechhra Union identified as particularly susceptible due to its limited adaptability and resilience, rendering it highly prone to flooding (Aktar, 2021).

This study aims (a) to analyze and compare the vulnerabilities of male-headed households (MHHs) and female-headed households (FHHs) in some selected unions of the Sirajganj Sadar Upazila, (b) to utilize a weightage average index (WAI) and statistical tests to measure and compare the levels of multidimensional vulnerability between FHHs and MHHs, and determine the significance of the differences observed, and (c) to identify the sociocultural norms and other factors contributing to the increased vulnerability of FHHs, and to recommend targeted interventions and strategies. The study employed a mixed methods design, which encompassed a survey targeting 216 households, 15 interviews with key informants, 40 comprehensive interviews, and 8 focus group discussions. The data were examined using the Weightage Average Index (WAI) for comparing levels of vulnerability and a t-test for evaluating statistical significance. The vulnerability assessment conducted in this research yields valuable insights for quantifying household flood risk, evaluating the extent of household vulnerability, and formulating essential policies and interventions aimed at mitigating flood risk and fostering community resilience

## 2. METHODS

### 2.1. Study Area

Sirajganj Sadar Upazila, situated within the confines of Sirajganj district, encompasses an area of 320.15 square kilometers, positioned between the latitudinal coordinates of 24°22' and 24°37' north, as well as the longitudinal coordinates of 89°36' and 89°47' east. This Upazila is geographically bordered to the north by Kazipur Upazila, to the south by Kamarkhanda and Belkuchi Upazilas, to the east by Sarishabari and Kalkhata Upazilas, and to the west by Kamarkhanda, Raiganj, and Dhunat Upazilas (Fig. 1).

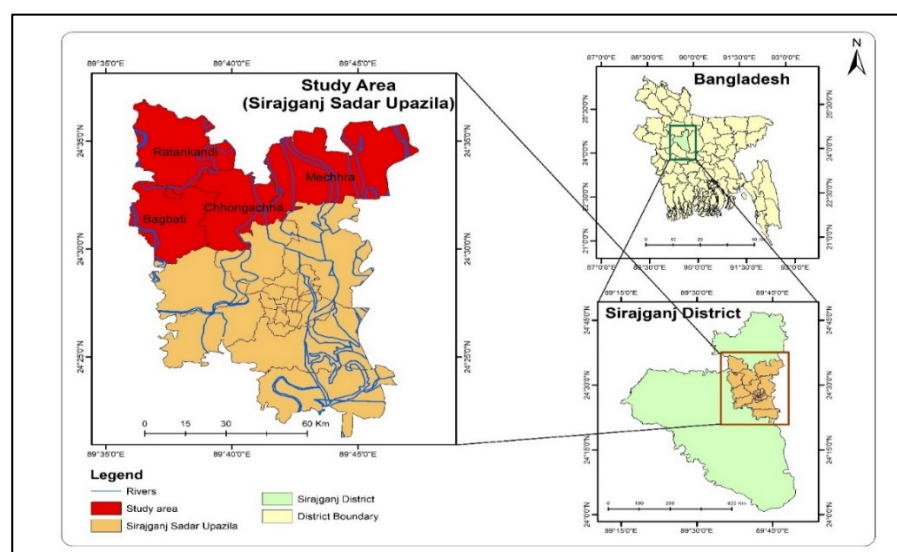


Figure 1. Study Area Map

Sirajganj Sadar Upazila is situated within the Jamuna-Karotoya Floodplain at the junction of the Ganges and Jamuna Rivers, characterized by its gently undulating flat terrain interspersed with numerous low-lying depressions (Samsuzzaman, 2003). Each year, this Upazila experiences flooding during the monsoon season, specifically from July to September. Every union within this Upazila is susceptible to flooding. Sirajganj Sadar Upazila is administratively segmented into Sirajganj Municipality and ten union parishads: Bagbati, Bohuli, Kaliahoripur, Khokshabari, Kawakhola, Mechhra, Ratankandi, Shialkol, Chhangachha, and Soydabad. Out of the ten union parishads of the upazila, four unions (Mechhra, Ratankandi, Baghbati, and Chhangachha) have been selected for the purpose of this study. As articulated by Akter (2021), the four union parishads within the Sirajganj Sadar upazila exhibit a noteworthy level of susceptibility to flooding, with the Mechhra Union being distinguished as especially vulnerable owing to its constrained capacity for adaptation and resilience, which consequently makes it exceedingly prone to inundation.

## 2.2 Research Design and Methods

Using both quantitative and qualitative research methodology this research adopted a mix research methodology to collect and analyze the data. The goal of the mix-method approach is to validate, corroborate, and supplement the data and findings. It also offers a more thorough interpretation of the data, enabling a full solution to the study problem (Creswell, 2003).

### 2.2.1 Household survey and sampling

Mixed sampling strategies were used in this study, including nonprobability sampling for cluster selection and simple random sampling for household selections. These techniques were chosen considering the research aims and the variables (MHHs and FHHs in the flood-prone community). Utilizing the Yamane (1987) formula [ $n = N / (1 + N(e)^2)$ ], a sample comprising 216 households was systematically drawn from a total population of 14,020 households for quantitative data collection in the household survey (Mechhra: M-39, F-39; Ratankandi: M-26, F-26; Baghbati: M-21, F-21; Chhangachha: M-22, F-22).

In order to strengthen the reliability of the statistical analysis for this study, a method of sampling with equal-sized samples was employed. The primary objective was to enable a comparison examination of households headed by males (MHHs) and households headed by females (FHHs). The sample size was carefully chosen using a procedure with a 95% confidence level and a 7% precision rate. Considering the villages under study had similar socio-economic and cultural origins, a precision rate of 7% was considered suitable. As therefore, interviews were carried out with an equal number of male-headed households (MHH) and female-headed households (FHH), with a total of 108 respondents from each category. The decision to use a non-proportional sample strategy was deliberate in order to highlight the study's emphasis on female-headed households (FHHs) while also adding male-headed households (MHHs) for comparative analysis.

### 2.2.2 In depth Interviews (IDIs) and Focus Group Discussion (FGD)

Subsequent to the household survey, in-depth interviews (IDIs) were conducted with 20 male-headed households (MHHs) and 20 female-headed households (FHHs), including 5 MHHs and 5 FHHs from each of the four unions. These interviews were designed to elucidate the underlying causes and mechanisms associated with the survey findings, providing rich, narrative data. This was followed by

the administration of eight focus group discussions (FGDs)—two in each community. The selection of FGD participants was facilitated with assistance from local village representatives and women's groups.

### 2.2.3 Key Informant Interviews (KII)

A total of fifteen Key Informant Interviews (KIIs) were performed with the leaders of the communities, local Disaster Risk Reduction (DRR) Committee, and local Non-Governmental Organization (NGO). These interviews were complemented by a household (HH) survey, which utilized structured questionnaires containing both multiple choice and Likert scale questions. The purpose of the survey was to gather details regarding the responses regarding their experiences with disasters.

## 2.3 Indicator Selection, Weights, and Composite Index

This study utilized the composite index (CI) approach to evaluate the gender perspective of household-based vulnerability for flooding catastrophes. The composite index (CI) method is a valuable tool for assessing gender perspectives in household-based flood vulnerability to flood disasters. Research from various contexts highlights the importance of considering gender dynamics in vulnerability assessments (Islam et al., 2011; Dhungel & Ojha, 2012; Rakib et al., 2017; Leya et al., 2020; Jerin et al., 2023). After assigning weights to each class of indicators, the index for each component was derived by converting the initial data into suitable weights for the calculations of the composite index. As per the vulnerability model of UNISDR (2004), the primary drivers of disaster risk lie in the condition of four key aspects: social, physical, economic, and environmental vulnerabilities. In order to reduce the likelihood of disasters, these vulnerabilities need to be assessed and solved. This study analyzed four particular variables using an index-based method to measure the gender perception of flood vulnerability in households.

To facilitate a precise and unambiguous interpretation of the Social Vulnerability Index (SVI), Physical Vulnerability Index (PVI), Economic Vulnerability Index (EVI), and Environmental Vulnerability Index (EnVI), households were categorized into four distinct classes of vulnerability (low, moderate, high, and very high) using the quartile method. This classification was conducted to comprehensively assess the extent of vulnerability to flood disasters among male-headed households (MHH) and female-headed households (FHH). A t-test was undertaken to discern the differences between Male-Headed Households (MHHs) and Female-Headed Households (FHHs) across multiple components. To further elucidate gender-based vulnerabilities, comprehensive indices were formulated, integrating all the indicators detailed in Table 1.

**Table 1.** List of selected indicators for household-level vulnerability assessment and their measurement methods, with weights and interpretation of respective empirical studies.

| Social Vulnerabilities |                              |            |         |                                 |                   |
|------------------------|------------------------------|------------|---------|---------------------------------|-------------------|
| SN                     | Indicators                   | Data Class | Weights | Interpretation                  | Empirical Studies |
| S1                     | Household Size of Respondent | <5         | 0.33    | The higher the family size, the |                   |
|                        |                              | 6-9        | 0.66    |                                 |                   |
|                        |                              | >10        | 1       |                                 |                   |

|           |                                                                                |                     |      |                                                                                                                   |                                              |
|-----------|--------------------------------------------------------------------------------|---------------------|------|-------------------------------------------------------------------------------------------------------------------|----------------------------------------------|
|           |                                                                                |                     |      | greater the vulnerability                                                                                         | (Cutter et al., 2012; Birkmann et al., 2013) |
| <b>S2</b> | Households with dependent family members                                       | No                  | 0    | Infant, children and elderly persons are more vulnerable than young and adult people because they are less mobile | (Armaş, 2012; Yoon, 2012)                    |
|           |                                                                                | Yes                 | 1    |                                                                                                                   |                                              |
| <b>S3</b> | Households having family members with chronic illness/ pregnancy or disability | No                  | 0    | Households with special needs will hinder mobility in case of emergency                                           | (Hahn, 2009; Kaźmierczak & Cavan, 2011)      |
|           |                                                                                | Yes                 | 1    |                                                                                                                   |                                              |
| <b>S4</b> | Level of educational attainment                                                | Illiterate          | 1    | The lower the educational level, the higher the vulnerability                                                     | (Armaş, 2012)                                |
|           |                                                                                | Literate            | 0.33 |                                                                                                                   |                                              |
|           |                                                                                | Primary (1–7)       | 0.5  |                                                                                                                   |                                              |
|           |                                                                                | Secondary (8–10)    | 0.67 |                                                                                                                   |                                              |
|           |                                                                                | High School (11–12) | 0.83 |                                                                                                                   |                                              |
|           |                                                                                | Graduate            | 0    |                                                                                                                   |                                              |
| <b>S5</b> | Households having a family member who can swim                                 | Yes                 | 0    | Swimming skills will increase capacity as it will help save lives and household items                             | (Jonkman & Kelman, 2005)                     |
|           |                                                                                | No                  | 1    |                                                                                                                   |                                              |
| <b>S6</b> | Households having a family member who has First Aid Knowledge                  | Yes                 | 0    | First aid knowledge will increase capacity by helping injured households and saving lives                         | (Blaikie, 2014)                              |
|           |                                                                                | No                  | 1    |                                                                                                                   |                                              |
| <b>S7</b> | Strength of community cooperation in disaster response                         | Very Good           | 0.2  | Cooperation strength represents the community's help and shared resources to cope with floods                     | (Flanagan et al., 2011)                      |
|           |                                                                                | Good                | 0.4  |                                                                                                                   |                                              |
|           |                                                                                | Moderate            | 0.6  |                                                                                                                   |                                              |
|           |                                                                                | Poor                | 0.8  |                                                                                                                   |                                              |
|           |                                                                                | Very Poor           | 1    |                                                                                                                   |                                              |
| <b>S8</b> | Households' participation in awareness training on flood preparedness          | Yes                 | 0    | Awareness about flood preparedness and protocols will help prepare households for floods                          | (Blaikie, 2014)                              |
|           |                                                                                | No                  | 1    |                                                                                                                   |                                              |

|                          |                                                                           |                          |         |                                                                                                                                              |                         |
|--------------------------|---------------------------------------------------------------------------|--------------------------|---------|----------------------------------------------------------------------------------------------------------------------------------------------|-------------------------|
| S9                       | Household-level trust in Government's DRR plan/program                    | Very High                | 0.2     | Household not having trust in government plan and programs mean they will not follow them and increase household vulnerability               | (Rana & Routray, 2018)  |
|                          |                                                                           | High                     | 0.4     |                                                                                                                                              |                         |
|                          |                                                                           | Moderate                 | 0.6     |                                                                                                                                              |                         |
|                          |                                                                           | Low                      | 0.8     |                                                                                                                                              |                         |
|                          |                                                                           | Very Low                 | 1       |                                                                                                                                              |                         |
| S10                      | Household-level trust in religious organizations to get effective support | Very High                | 0.2     | Household not having trust means the community cooperation will not be stronger and increase household vulnerability                         | (Mitchell, 1999)        |
|                          |                                                                           | High                     | 0.4     |                                                                                                                                              |                         |
|                          |                                                                           | Moderate                 | 0.6     |                                                                                                                                              |                         |
|                          |                                                                           | Low                      | 0.8     |                                                                                                                                              |                         |
|                          |                                                                           | Very Low                 | 1       |                                                                                                                                              |                         |
| Physical Vulnerabilities |                                                                           |                          |         |                                                                                                                                              |                         |
| SN                       | Indicators                                                                | Data Class               | Weights | Interpretation                                                                                                                               | Empirical Studies       |
| P1                       | HH used the materials to construct the house                              | Full cemented            | 0.2     | Houses made of bamboo and straw are more vulnerable                                                                                          | (Thouret et al., 2014)  |
|                          |                                                                           | Brick wall and Tin roof  | 0.4     |                                                                                                                                              |                         |
|                          |                                                                           | Wood/Bamboo and Tin roof | 0.6     |                                                                                                                                              |                         |
|                          |                                                                           | Wood/mud and Tin roof    | 0.8     |                                                                                                                                              |                         |
|                          |                                                                           | Bamboo/Straw             | 1       |                                                                                                                                              |                         |
| P2                       | HH having raised the plinth level of the house to survive the flood       | Yes                      | 0       | Households living in single-story residence or not having raised the plinth level for the single-story house will increase the vulnerability | (Balica, 2009)          |
|                          |                                                                           | No                       | 1       |                                                                                                                                              |                         |
| P3                       | HH has enough access to irrigation                                        | Very Good                | 0.2     | Households having irrigation can support agriculture production for food security that reduces the vulnerability                             | (Mazumdar & Paul, 2016) |
|                          |                                                                           | Good                     | 0.4     |                                                                                                                                              |                         |
|                          |                                                                           | Moderate                 | 0.6     |                                                                                                                                              |                         |
|                          |                                                                           | Poor                     | 0.8     |                                                                                                                                              |                         |
|                          |                                                                           | Very Poor                | 1       |                                                                                                                                              |                         |
| P4                       | HH having any kind of vehicle for transportation                          | Yes                      | 0       | A household with no means of transportation will be hindered in evacuation                                                                   | (Mazumdar & Paul, 2016) |
|                          |                                                                           | No                       | 1       |                                                                                                                                              |                         |



|                          |                                                                                                  |                     |         |                                                                                                                                                    |                       |
|--------------------------|--------------------------------------------------------------------------------------------------|---------------------|---------|----------------------------------------------------------------------------------------------------------------------------------------------------|-----------------------|
| P5                       | HH having reliable means of communication for early warning message                              | Very reliable       | 0.2     | Households with no access to means of communication will be more vulnerable                                                                        | (Khan, 2012)          |
|                          |                                                                                                  | Reliable            | 0.4     |                                                                                                                                                    |                       |
|                          |                                                                                                  | Moderate            | 0.6     |                                                                                                                                                    |                       |
|                          |                                                                                                  | Less reliable       | 0.8     |                                                                                                                                                    |                       |
|                          |                                                                                                  | Worst reliable      | 1       |                                                                                                                                                    |                       |
| P6                       | Households having managed alternate water sources in disaster                                    | Yes                 | 0       | Households are more vulnerable to not having alternative sources of drinking water                                                                 | (Armaş, 2012)         |
|                          |                                                                                                  | No                  | 1       |                                                                                                                                                    |                       |
| Economic Vulnerabilities |                                                                                                  |                     |         |                                                                                                                                                    |                       |
| SN                       | Indicators                                                                                       | Data Class          | Weights | Interpretation                                                                                                                                     | Empirical Studies     |
| E1                       | Average Monthly Household’s Income (in NPR Amount)                                               | 75,000–100,000      | 0.25    | Lower income results in higher vulnerability and more time to recover from flood                                                                   | (Holand, 2011)        |
|                          |                                                                                                  | 50,000–75,000       | 0.75    |                                                                                                                                                    |                       |
|                          |                                                                                                  | 25,000–50,000       | 0.5     |                                                                                                                                                    |                       |
|                          |                                                                                                  | <25,000 NPR         | 1       |                                                                                                                                                    |                       |
| E2                       | Main income source of household (Agriculture/ Daily wages/ business/ Remittances/regular salary) | Employment (Salary) | 0.2     | Agriculture-dependent people are the most vulnerable and an unstable source of income from a particular occupation will increase the vulnerability | (Holand, 2011)        |
|                          |                                                                                                  | Remittances         | 0.4     |                                                                                                                                                    |                       |
|                          |                                                                                                  | Business            | 0.6     |                                                                                                                                                    |                       |
|                          |                                                                                                  | Daily Wage          | 0.8     |                                                                                                                                                    |                       |
|                          |                                                                                                  | Agriculture         | 1       |                                                                                                                                                    |                       |
| E3                       | Households having multiple sources of income                                                     | 5                   | 0.2     | Multiple sources of livelihood will increase capacity because even if one source is cut off, households can survive on another                     | (Nhuan et al., 2016)  |
|                          |                                                                                                  | 4                   | 0.4     |                                                                                                                                                    |                       |
|                          |                                                                                                  | 3                   | 0.6     |                                                                                                                                                    |                       |
|                          |                                                                                                  | 2                   | 0.8     |                                                                                                                                                    |                       |
|                          |                                                                                                  | 1                   | 1       |                                                                                                                                                    |                       |
| E4                       | Average Monthly Households Savings (in NPR Amount)                                               | >1001               | 0.2     | Savings will increase the capacity to cope with floods and will help in recovery that makes households less                                        | (Browne & Hoyt, 2000) |
|                          |                                                                                                  | 501–1000            | 0.4     |                                                                                                                                                    |                       |
|                          |                                                                                                  | 201–500             | 0.6     |                                                                                                                                                    |                       |
|                          |                                                                                                  | 101–200             | 0.8     |                                                                                                                                                    |                       |
|                          |                                                                                                  | <100                | 1       |                                                                                                                                                    |                       |

|                               |                                                                                                                                            |                 |         |                                                                                                                                                                                                                |                              |
|-------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|-----------------|---------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|------------------------------|
|                               |                                                                                                                                            |                 |         | vulnerable to flood                                                                                                                                                                                            |                              |
| E5                            | Households having any kind of insurance (Life, Health)                                                                                     | Yes             | 0       | Insurance will increase coping capacity and help households in recovery after floods                                                                                                                           | (Browne & Hoyt, 2000)        |
|                               |                                                                                                                                            | No              | 1       |                                                                                                                                                                                                                |                              |
| E6                            | Average Value of having other resources of Household (bank balance, cash, gold/silver, farm animals, share, or any others) (in NPR Amount) | >20,000         | 0.2     | Households having other resources that can be sold during a crisis will decrease the vulnerability                                                                                                             | (Browne & Hoyt, 2000)        |
|                               |                                                                                                                                            | 150,001–200,000 | 0.4     |                                                                                                                                                                                                                |                              |
|                               |                                                                                                                                            | 100,001–150,000 | 0.6     |                                                                                                                                                                                                                |                              |
|                               |                                                                                                                                            | 50,001–100,000  | 0.8     |                                                                                                                                                                                                                |                              |
|                               |                                                                                                                                            | <50,000         | 1       |                                                                                                                                                                                                                |                              |
| Environmental Vulnerabilities |                                                                                                                                            |                 |         |                                                                                                                                                                                                                |                              |
| SN                            | Indicators                                                                                                                                 | Data Class      | Weights | Interpretation                                                                                                                                                                                                 |                              |
| En1                           | Households having clean/safe piped drinking water                                                                                          | Yes             | 0       | Households with no access to safe drinking water will be at more risk                                                                                                                                          | (Panthi et al., 2016)        |
|                               |                                                                                                                                            | No              | 1       |                                                                                                                                                                                                                |                              |
| En2                           | Household using an open place for defecating (Open toilet)                                                                                 | No              | 0       | Open defecation can pollute the environment and cause health problems and lead to vulnerability                                                                                                                | (Rasch, 2016)                |
|                               |                                                                                                                                            | Yes             | 1       |                                                                                                                                                                                                                |                              |
| En3                           | Households having a sewage disposal system                                                                                                 | Yes             | 0       | Households not having sewage disposal systems are more vulnerable to the surrounding environment                                                                                                               | (Balica & Wright, 2010)      |
|                               |                                                                                                                                            | No              | 1       |                                                                                                                                                                                                                |                              |
| En4                           | Households having open disposal of animal waste (ODAW)                                                                                     | No              | 0       | Open disposal of animal waste provides breeding sites for insects, pests, snakes and vermin (rats) that increase the likelihood of disease transmission. It may also pollute water sources and the environment | (Adam-Bradford et al., 2012) |
|                               |                                                                                                                                            | Yes             | 1       |                                                                                                                                                                                                                |                              |
| En5                           | Households having farmland covered by sand/debris                                                                                          | No              | 0       | Sediment and debris barriers to crop production and physical damage to the soil and plants that affect the environment                                                                                         | (Higaki & Sato, 2012)        |
|                               |                                                                                                                                            | Yes             | 1       |                                                                                                                                                                                                                |                              |

|            |                       |           |     |                                         |                           |
|------------|-----------------------|-----------|-----|-----------------------------------------|---------------------------|
| <b>En6</b> | Households using      | Very High | 1   | Chemical fertilizers                    | (Taubenböck et al., 2008) |
|            | chemical              | High      | 0.8 | cause land and water                    |                           |
|            | Fertilizer/pesticides | Moderate  | 0.6 | pollution and the                       |                           |
|            | to increase crops'    | Low       | 0.4 | chemical content of the                 |                           |
|            | productivity          | Very Low  | 0.2 | crop leads to damage to the environment |                           |

The primary dataset served as a foundation for employing a subjectively weighted technique, which facilitated the assignment of specific values to distinct classes of phenomena pertaining to each indicator. Building upon this, indices were subsequently developed in accordance with Equation (1). The selection of these indicators drew from a rich tapestry of empirical research in the fields of disaster risk science and climate change. Each indicator underwent a rigorous evaluation, specifically tailored to local conditions, and was refined as needed to enhance its relevance and applicability. Ten parameters were utilized for the social component and six indicators were employed for physical, economic, and environmental components. Each component has been accorded equivalent relevance, as all unions endure flood dangers primarily due of the Koshi River. Consequently, a mean value was calculated for all parameters to analyze the multidimensional vulnerability index for male-headed households (MHH) and female-headed households (FHH).

The estimation for the headship-based vulnerability composite index in this study employed the data calculation method from prior empirical flood risk evaluations keeping to the initial equation as the reference.

$$CI = (W_1 + W_2 + \dots + W_n) / n = \sum_{i=1}^n \frac{W_i}{n} \quad (1)$$

The composite index (CI) is derived using the weightages of transformed indicator values ( $W_1$  to  $W_n$ ) and the number of indicators ( $n$ ), a method employed in this study to calculate the SVI, PVI, EVI, and EnVI for each sampled household.

The CI stands for the composite index,  $W_1$  to  $W_n$  are the weightage of individually transformed values of indicators, and  $n$  is the number of indicators used in particular components for computing the composite index. Following this general principle, this study calculated the SVI, PVI, EVI, and EnVI of every sampled household. Furthermore, the Multidimensional Vulnerability Index (MVI) was computed using Equation (2) for both MHHs and FHHs.

$$\text{Social Vulnerability Index (SVI)} = \sum_{i=1}^{10} SW_i / n; (n = 10)$$

$$\text{Physical Vulnerability Index (PVI)} = \sum_{i=1}^6 PW_i / n; (n = 6)$$

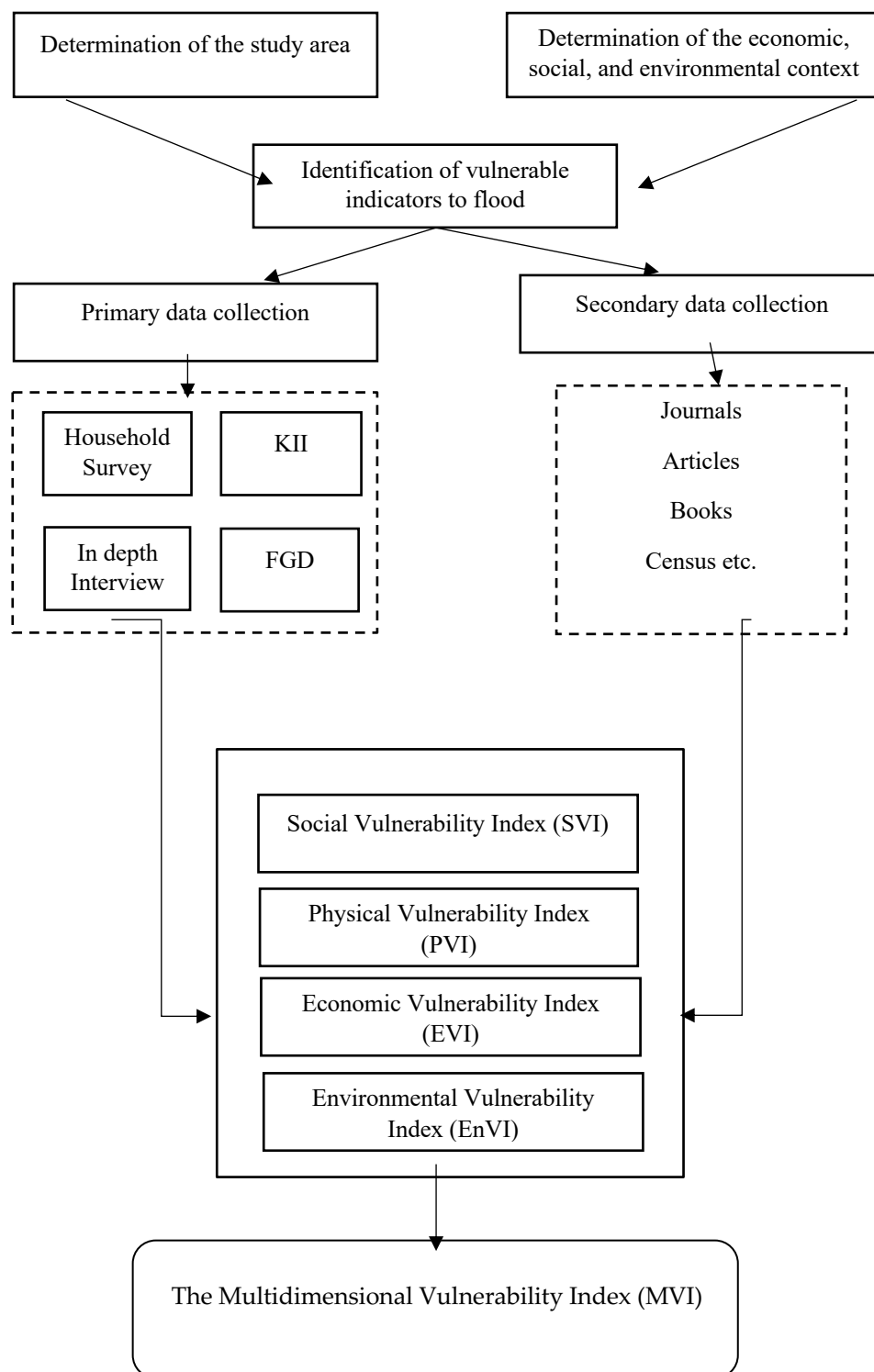
$$\text{Economic Vulnerability Index (EVI)} = \sum_{i=1}^6 EW_i / n; (n = 6)$$

$$\text{Environmental Vulnerability Index (EnVI)} = \sum_{i=1}^6 EnW_i / n; (n = 6)$$

$$\text{The Multidimensional Vulnerability Index (MVI)} = \frac{SVI + PVI + EVI + EnVI}{4} \quad (2)$$

Using the WAI technique, original indicator values were transformed to a 0-1 scale based on vulnerability levels, where 0 indicates low vulnerability and 1 indicates high vulnerability. Variables were classified into categories depending on their characteristics, ranging from two classes (yes/no) to

six classes, with values assigned accordingly. For example, dual classes were assigned 0 and 1; three classes were assigned 0.33, 0.66, and 1; four classes were assigned 0.25, 0.50, 0.75, and 1; five classes were assigned 0.2, 0.4, 0.6, 0.8, and 1; six classes were assigned 0, 0.83, 0.67, 0.5, 0.33, and 1. Consequently, the composite index for each component ranged between 0 and 1.



**Figure 2.** Methodological workflow

The research method should be included in the Introduction. The method contains an explanation of the research approach, study subjects, the research procedure's conduct, the use of materials and instruments, data collection, and analysis techniques.

### 3. FINDINGS AND DISCUSSION

The results obtained from the research have to be supported by sufficient data. The research results and the discovery must be the answers or the research hypothesis stated previously in the introduction part.

#### 3.1 Demographic Profile

Table 2 outlines the demographic characteristics of 108 respondents each from Male-Headed Households (MHHs) and Female-Headed Households (FHHs). A larger share of younger respondents (21–30 years) is observed in FHHs (15%) compared to MHHs (5%), while middle-aged individuals (31–50 years) are more common in MHHs. Most households in both groups (47%) consist of 6–9 members. Monthly income below 25,000 BDT is reported by 80% of MHHs and 53% of FHHs. Illiteracy is higher among FHHs (32%) than MHHs (24%), while MHHs show higher educational attainment overall. Occupation-wise, 70% of MHHs rely solely on agriculture, whereas 79% of FHHs engage in both household work and agriculture. The majority of respondents are Muslim—75% in MHHs and 67% in FHHs.

**Table 2.** Demographic profile of the respondents (percentage)

| Profile           | Description      | MHH ( <i>n</i> = 108) | FHH ( <i>n</i> = 108) | Total ( <i>n</i> = 216) |
|-------------------|------------------|-----------------------|-----------------------|-------------------------|
| Age               | 21-30            | 5                     | 15                    | 10                      |
|                   | 31-40            | 32                    | 22                    | 27                      |
|                   | 41-50            | 36                    | 22                    | 29                      |
|                   | 51-60            | 30                    | 15                    | 22                      |
|                   | 61-70            | 14                    | 7                     | 11                      |
|                   | >71              | 2                     | 1                     | 1                       |
| Household Size    | <5               | 49                    | 45                    | 47                      |
|                   | 6-9              | 47                    | 47                    | 47                      |
|                   | >10              | 9                     | 3                     | 6                       |
| Monthly HH Income | <25,000 BDT      | 80                    | 53                    | 67                      |
|                   | 25,000-50,000    | 34                    | 15                    | 25                      |
|                   | 50,000-75,000    | 6                     | 1                     | 3                       |
|                   | 75,000-100,000   | 5                     | 3                     | 4                       |
|                   | >100,000         | 2                     | 1                     | 1                       |
| Education         | Illiterate       | 24                    | 32                    | 28                      |
|                   | Literate         | 33                    | 21                    | 27                      |
|                   | Primary          | 22                    | 16                    | 19                      |
|                   | Secondary        | 25                    | 16                    | 20                      |
|                   | Higher Secondary | 8                     | 3                     | 5                       |

|                   |                         |    |    |    |
|-------------------|-------------------------|----|----|----|
|                   | Graduate and above      | 0  | 1  | 0  |
| <b>Occupation</b> | Agriculture             | 70 | 9  | 40 |
|                   | HH work                 | 1  | 6  | 4  |
|                   | HH work and agriculture | 0  | 79 | 39 |
|                   | Services                | 5  | 1  | 3  |
|                   | Wage labor              | 16 | 1  | 8  |
|                   | Business                | 7  | 7  | 6  |
|                   |                         |    |    |    |
| <b>Religion</b>   | Muslim                  | 75 | 67 | 71 |
|                   | Hindu                   | 29 | 21 | 25 |
|                   | Others                  | 4  | 4  | 4  |

### 3.2 Social Vulnerability

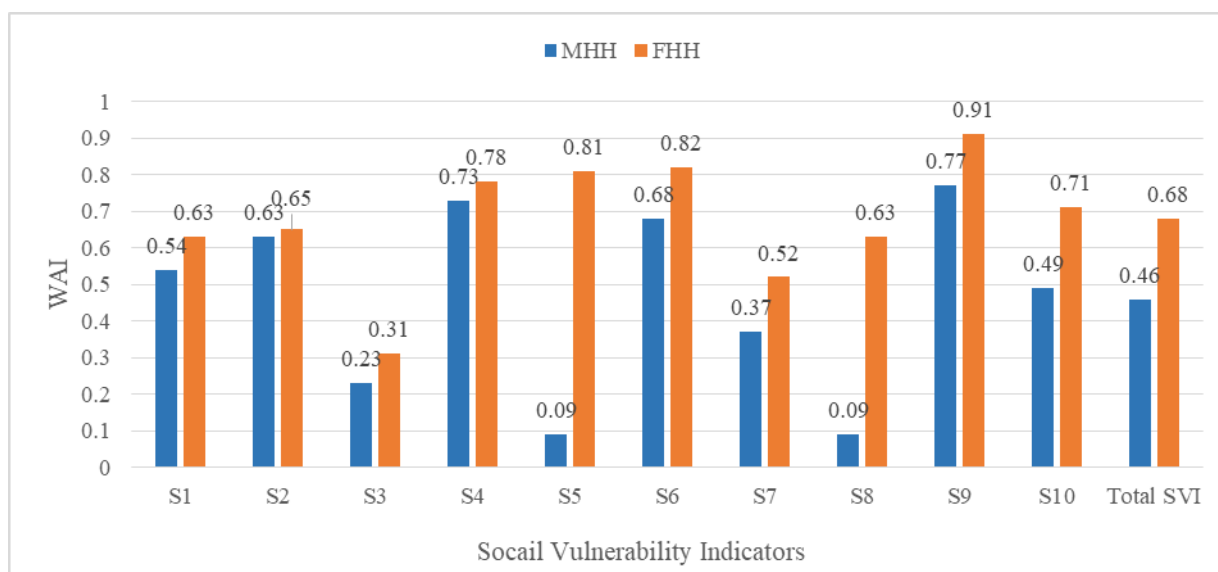
The table 3 presents household-level social vulnerability data for 108 households, comprising male-headed households (MHHs) and female-headed households (FHHs). Vulnerability is classified into four categories: Low (0.20–0.39), Moderate (0.39–0.58), High (0.58–0.77), and Very High (0.77–0.96). Among MHHs, 57.4% fall into the Low category, while only 4.6% of FHHs are in the same class. In contrast, 52.8% of FHHs are in the High category and 8.3% in the Very High, compared to just 5.6% and 0% for MHHs, respectively. The mean vulnerability score is 0.5706 (SD = 0.16381), ranging from 0.20 to 0.96. A T-test shows a significant difference between MHHs and FHHs ( $T = 1.106$ ,  $df = 214$ ,  $p = 0.000$ ).

**Table 3.** Household-level Social Vulnerability (MHH; n =108 and FHH; n =108)

| Gender      | Classes | Low       | Moderate  | High      | Very High | Descriptive Statistics        | T - Test              |
|-------------|---------|-----------|-----------|-----------|-----------|-------------------------------|-----------------------|
|             | Range   | 0.20-0.39 | 0.39-0.58 | 0.58-0.77 | 0.77-0.96 |                               |                       |
| <b>MHHs</b> | No.     | 62        | 40        | 6         | 0         | Min = 0.20<br>Max = 0.96      | F = 1.106<br>df = 214 |
|             | %       | 57.4      | 37        | 5.6       | 0         | Mean = 0.5706<br>SD = 0.16381 | p value = 0.000       |
| <b>FHHs</b> | No.     | 5         | 37        | 57        | 9         | Range = 0.76                  |                       |
|             | %       | 4.6       | 34.3      | 52.8      | 8.3       |                               |                       |
| <b>HHs</b>  | No.     | 67        | 77        | 63        | 9         |                               |                       |
|             | %       | 31.02     | 35.65     | 29.17     | 4.17      |                               |                       |

The Figure 3 (WAI results) further highlights FHHs' higher vulnerability. Key contributing factors include lower swimming ability (0.81 vs. 0.90), less participation in awareness programs (0.63

vs. 0.90), and weaker trust in religious organizations (0.71 vs. 0.49). A chi-square test confirms the swimming ability difference ( $\chi^2 = 113.64$ ,  $p = 0.000$ ), with 91% of MHHs having family members who can swim versus only 18% of FHHs.



**Figure 3.** Social Vulnerability Index (SVI) of MHHs and FHHs.

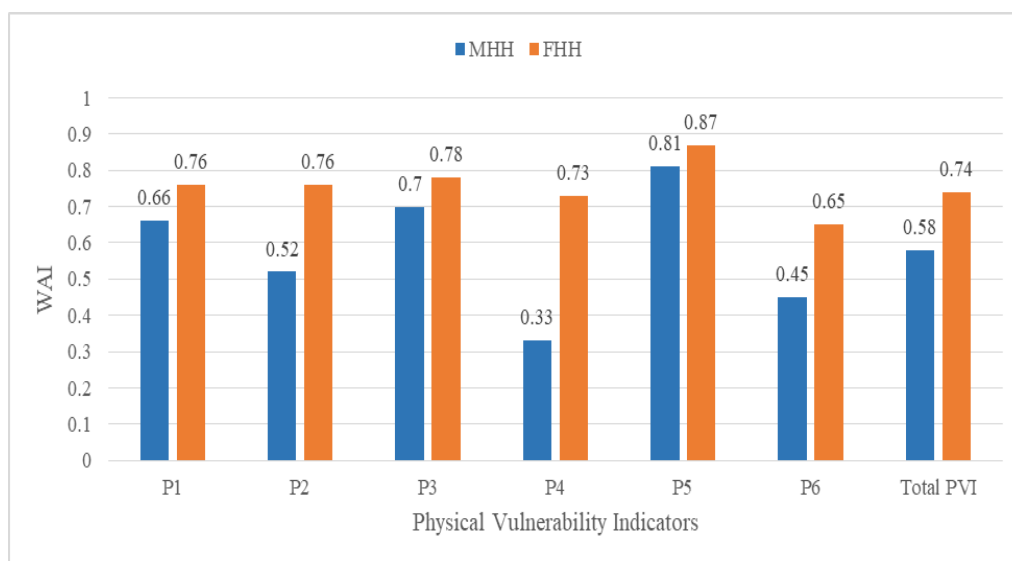
In-depth interviews (IDI, 2024) and focus group discussions (FGD, 2024) reveal barriers faced by FHHs, such as gender-biased training selection, household duties, and lack of inclusion in planning. While 91% of MHHs attended flood awareness programs, only 37% of FHHs did. Barriers include household workload (42%), lower priority (24%), age, confidence issues, and religious restrictions. Additionally, 47% of FHHs express low trust in religious groups compared to 2% of MHHs.

Family size and dependency ratios are similar across both groups. However, 31% of FHHs report members needing intensive care compared to 23% of MHHs. Educational levels show no significant difference ( $\chi^2 = 8.417$ ,  $p = 0.135$ ), though a large share of both groups lack formal education. Only 18% of FHHs report first aid knowledge in the household versus 32% of MHHs. Perceptions of community cooperation differ significantly ( $\chi^2 = 41.609$ ,  $p = 0.000$ ), with MHHs showing more trust. Trust in government disaster risk reduction (DRR) programs remains low across both groups (17% MHHs, 8% FHHs).

### 3.3 Physical Vulnerability

The physical vulnerability index ranges from 0.30 to 0.97, with FHHs scoring higher (0.74) than MHHs (0.58), indicating greater vulnerability among FHHs (Figure 4). About 27% of FHHs fall into the very high vulnerability category, compared to just 3% of MHHs, while 48% of FHHs and 34% of MHHs fall into the high category. This disparity is statistically significant ( $F = 4.533$ ,  $p = 0.000$ ) (Table 4).

Weighted Average Index (WAI) results show FHHs are more vulnerable across all indicators: 63% lack transportation, 76% haven't raised their plinth level, and 65% lack alternative drinking water sources. Only 2% of all houses are fully cemented—less than 1% of FHHs and around 3% of MHHs. A female respondent noted difficulties maintaining the house alone (IDI, 2024), while FGDs stressed that financial and labor limitations hinder house repairs (FGD, 2024).



**Figure 4.** Physical Vulnerability Index (PVI) of MHHs and FHHs.

Additionally, 92% of FHHs and 79% of MHHs lack reliable communication for early warnings. About 65% of FHHs and 45% of MHHs struggle to secure drinking water during floods. Agricultural irrigation access is also limited—74% of FHHs and 40% of MHHs lack access. Chi-square tests confirm significantly higher vulnerability in FHHs across most indicators ( $p = 0.000$ ), except early warning communication ( $p = 0.028$ ) and alternative drinking water ( $p = 0.004$ ).

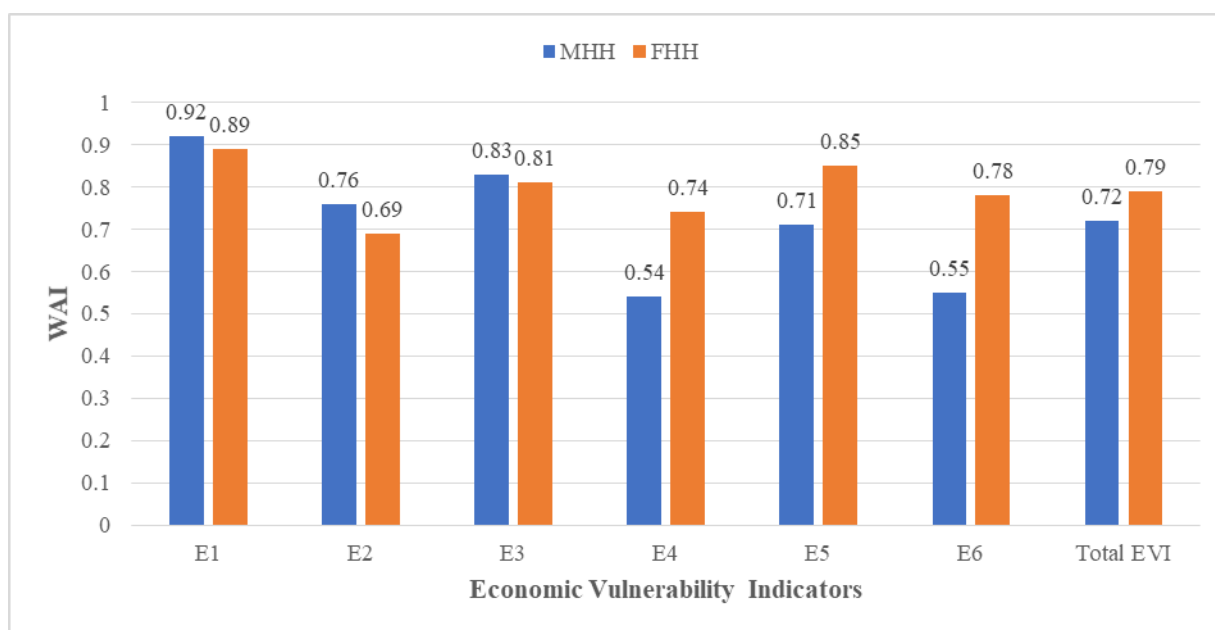
**Table 4.** Household-level Physical Vulnerability (MHH;  $n=108$  and FHH;  $n=108$ ).

| Gender | Classes | Low      | Moderate  | High      | Very High | Descriptive Statistics | T - Test             |
|--------|---------|----------|-----------|-----------|-----------|------------------------|----------------------|
|        | Range   | 0.3-0.47 | 0.47-0.64 | 0.64-0.80 | 0.80-0.97 | Min = 0.30             |                      |
| MHHs   | No.     | 25       | 43        | 37        | 3         | Max = 0.97             | F = 4.53<br>df = 214 |
|        | %       | 23.1     | 39.8      | 34.3      | 2.8       | Mean = 0.6602          |                      |
| FHHs   | No.     | 1        | 26        | 52        | 29        | SD = 0.16228           | p value = 0.000      |
|        | %       | 0.9      | 24.1      | 48.1      | 26.9      | Range = 0.67           |                      |
| HHs    | No.     | 26       | 69        | 89        | 32        |                        |                      |
|        | %       | 12.04    | 31.94     | 41.20     | 14.81     |                        |                      |

### 3.4 Economic Vulnerability

The Table 5 and Figure 5 illustrate that female-headed households (FHHs) are economically more vulnerable (mean score: 0.79) than male-headed households (MHHs) (mean score: 0.72), with a statistically significant difference ( $F = 5.597$ ,  $p = 0.000$ ). About 35% of FHHs fall into the very high economic vulnerability group, compared to 24% of MHHs, while 52% of FHHs and 44% of MHHs fall into the high category.





**Figure 5.** Economic Vulnerability Index (EVI) of MHHs and FHHs.

Though the average monthly income does not differ significantly between MHHs and FHHs ( $\chi^2 = 7.495$ ,  $p = 0.112$ ), FHHs are more exposed in terms of savings, insurance, and asset ownership. Around 71% of MHHs and 67% of FHHs earn less than NPR 25,000 per month, with FHHs relying more heavily on remittances (47%) due to the migration of 90% of their spouses. In contrast, 51% of MHHs rely primarily on agriculture, with 5% employed in salaried jobs—a category absent among FHHs.

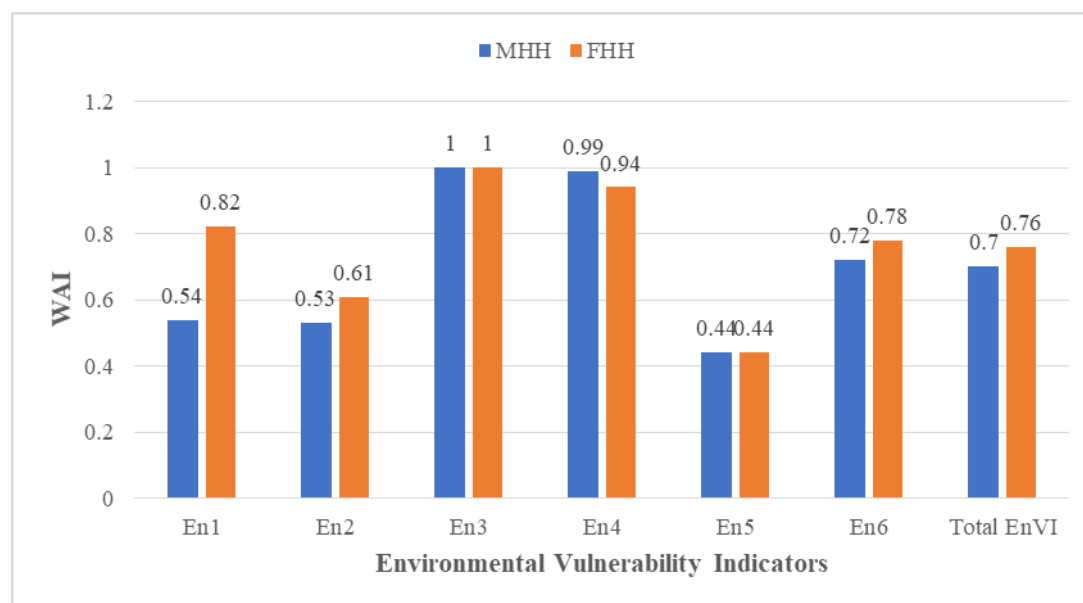
**Table 5.** Household-level Economic Vulnerability (MHH;  $n=108$  and FHH;  $n=108$ )

| Gender | Classes | Low       | Moderate  | High      | Very High | Descriptive Statistics                                                    | T - Test                                 |
|--------|---------|-----------|-----------|-----------|-----------|---------------------------------------------------------------------------|------------------------------------------|
|        | Range   | 0.19-0.39 | 0.39-0.58 | 0.58-0.78 | 0.78-0.97 | Min = 0.19<br>Max = 0.97<br>Mean = 0.7567<br>SD = 0.14178<br>Range = 0.78 | F = 5.597<br>df = 214<br>p value = 0.000 |
| MHHs   | No.     | 8         | 27        | 47        | 26        |                                                                           |                                          |
|        | %       | 7.4       | 25        | 43.5      | 24.1      |                                                                           |                                          |
| FHHs   | No.     | 0         | 14        | 56        | 38        |                                                                           |                                          |
|        | %       | 0         | 13        | 51.9      | 35.2      |                                                                           |                                          |
| HHs    | No.     | 8         | 41        | 103       | 64        |                                                                           |                                          |
|        | %       | 3.70      | 18.98     | 47.69     | 29.63     |                                                                           |                                          |

Savings practices reveal a notable gap: MHHs report higher monthly savings, while 85% of FHHs lack insurance coverage compared to 71% of MHHs. Furthermore, FHHs tend to have fewer household assets and face higher daily living costs. Limited income diversification and dependency on absent male members for major financial decisions further constrain their economic resilience, making FHHs more financially vulnerable despite receiving remittances.

### 3.5 Environmental Vulnerability

Figure 6 illustrates the vulnerability index (WAI) for both male-headed households (MHHs) and female-headed households (FHHs). Notably, FHHs exhibit a higher vulnerability status (WAI = 0.76) compared to MHHs (WAI = 0.70).



**Figure 6.** Environmental Vulnerability Index (EnVI) of MHHs and FHHs.

Analyzing household-level environmental vulnerability, we find that 20% of MHHs and 31% of FHHs fall into the ‘very high’ vulnerability category. Additionally, 32% of MHHs and 36% of FHHs are classified as ‘high’ vulnerability households (see Table 6). A t-test reveals a highly significant difference ( $F = 24.45$ ,  $p\text{-value} = 0.000$ ) between MHHs and FHHs in terms of environmental vulnerability. In our evaluation of environmental vulnerability amongst male-headed households (MHHs) and female-headed households (FHHs), we considered six critical factors. Notably, 54% of MHHs lack access to pipe-supplied drinking water, while this proportion jumps to 82% for FHHs. Additionally, 53% of MHHs and 61% of FHHs rely on open toilets for sanitation. Importantly, none of the respondents have access to a sewage disposal system, and 99% of MHHs and 94% of FHHs publicly disposing of animal excrement. Moreover, methods of agriculture play an important part in susceptibility. Approximately 81% of FHHs and 57% of MHHs utilize a large number of chemical fertilizers and pesticides to boost crop productivity.

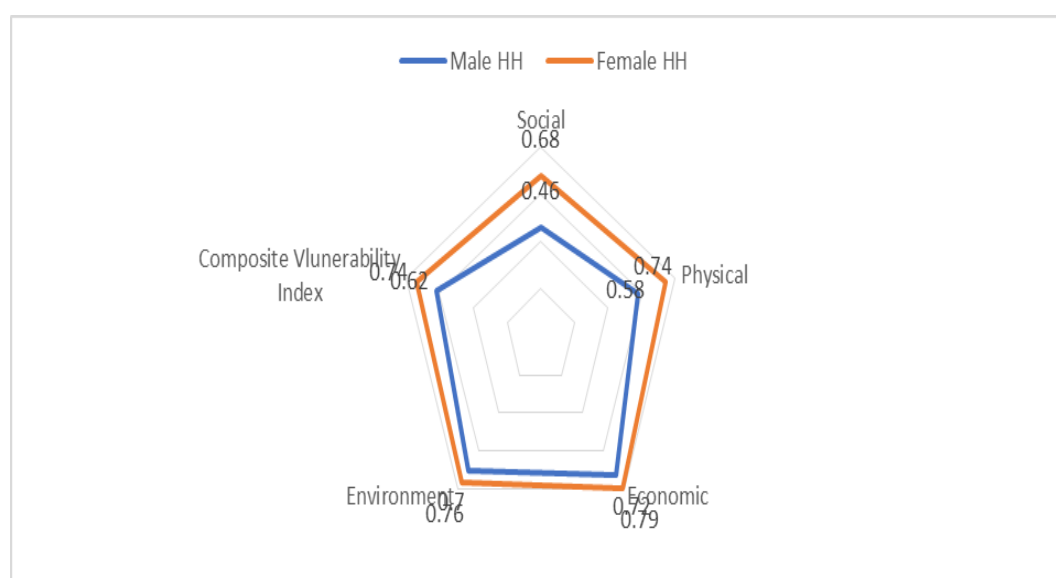
**Table 6.** Household-level Environmental Vulnerability (MHH;  $n=108$  and FHH;  $n=108$ ).

| Gender | Classes | Low       | Moderate  | High     | Very High | Descriptive Statistics   | T - Test                  |
|--------|---------|-----------|-----------|----------|-----------|--------------------------|---------------------------|
|        | Range   | 0.30-0.48 | 0.48-0.65 | 0.65-0.8 | 0.83-1.00 | Min = 0.30<br>Max = 1.00 | $F = 2.475$<br>$df = 214$ |
| MHHs   | No.     | 21        | 31        | 34       | 22        | Mean = 0.7333            | $p\text{ value} = 0.000$  |
|        | %       | 19.4      | 28.7      | 31.5     | 20.4      | SD = 0.18230             |                           |
| FHHs   | No.     | 11        | 25        | 39       | 33        | Range = 0.70             |                           |
|        | %       | 10.2      | 23.1      | 36.1     | 30.6      |                          |                           |

| HHs | No. | 32    | 56    | 73    | 55    |
|-----|-----|-------|-------|-------|-------|
|     | %   | 14.81 | 25.93 | 33.80 | 25.46 |

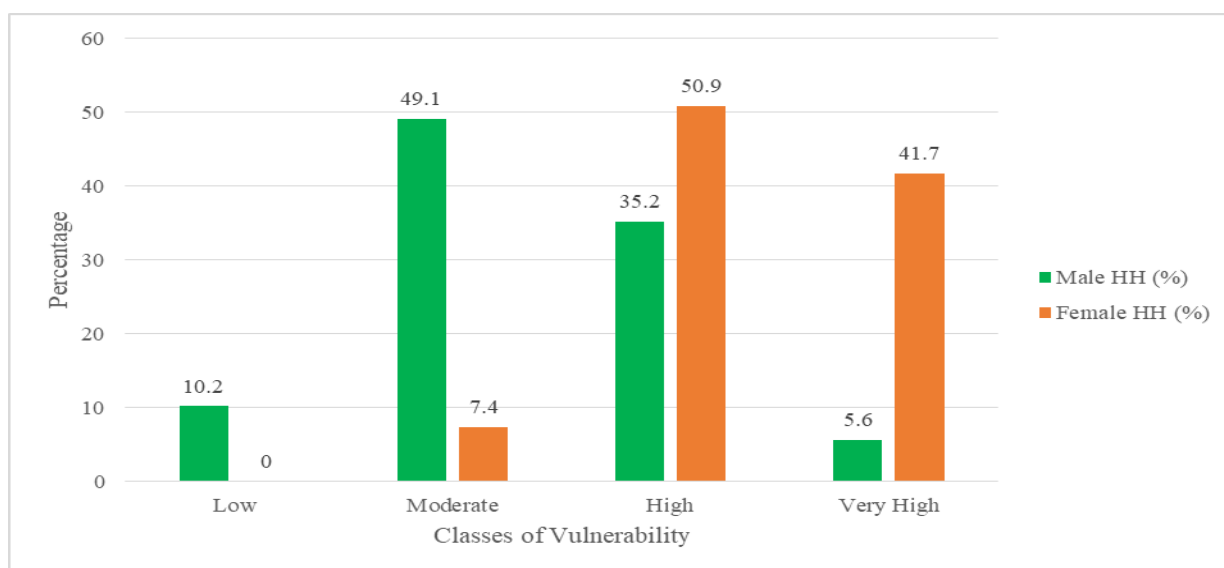
### 3.6 The Multidimensional Vulnerabilities

The composite index reveals that female-headed households (FHHs) experience higher overall vulnerability across all dimensions—social, physical, economic, and environmental—compared to male-headed households (MHHs). Figure 7 highlights that the disparity is particularly pronounced in the social and physical domains. Although FHHs benefit from remittance-based income, their financial vulnerability remains high due to limited savings and increased expenditures. In contrast, MHHs are more exposed in terms of income sources and environmental challenges such as waste management.



**Figure 7.** The Gender-Based Multidimensional Composite Vulnerability Index of MHHs and FHHs.

Statistical analysis confirms a significant difference in multidimensional vulnerability between FHHs and MHHs ( $F = 3.423$ ,  $p < 0.001$ ), with vulnerability scores ranging from 0.57 to 0.89 for FHHs and 0.37 to 0.80 for MHHs. According to the Weighted Average Index (Figure 8), 42% of FHHs fall into the very high vulnerability category and 51% into the high category, while MHHs are more concentrated in moderate (49%) and low (10%) vulnerability groups.



**Figure 8.** Total Vulnerability Index of MHHs and FHHs.

Component-wise WAI scores show economic vulnerability is the highest for both FHHs (0.79) and MHHs (0.72), followed by environmental (0.76 and 0.70), physical (0.74 and 0.58), and social (0.68 and 0.46) components. These findings underscore the need for targeted interventions focusing on capacity building, inclusive planning, livelihood support, and increased female participation in disaster preparedness to reduce gendered vulnerability disparities.

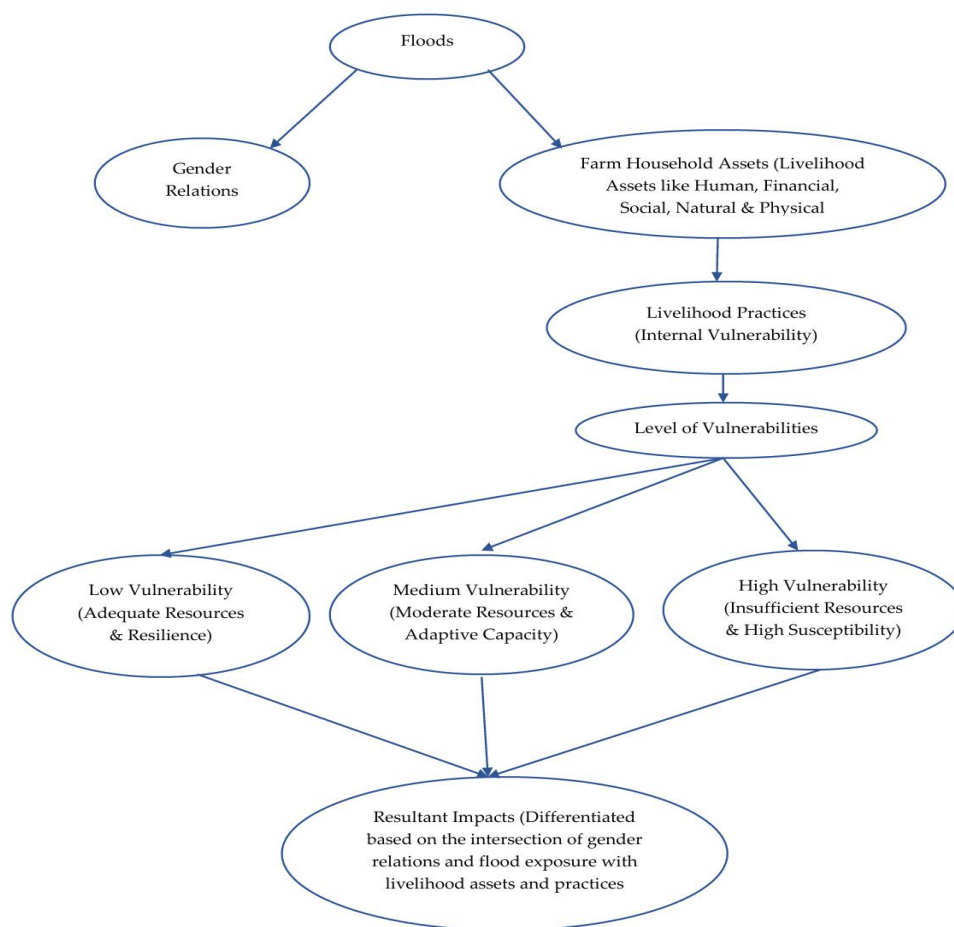
The multitude of parental obligations severely restricts women's involvement in disaster-preparedness initiatives, leading to distinguishing vulnerabilities. Furthermore, to flood concerns, this study found involvement in communal endeavors, income-related making choices, and dependence on relatives for support as factors that contribute to the increased vulnerability of female-headed households (FHHs). Additionally, relatively concealed elements, such as gender disparities in community power of negotiation and the impact of social and legal organizations, substance this issue (Chant, 2007). The study emphasizes that men's general influence over income and resources extends to decision-making, even in their physical presence from the household. This shows the existence of sources of different vulnerability and traits particular to FHHs. Specifically, it shows that female heads of houses generally have limited social networks and constrained involvement in organizations of society. This restriction is partly due to their lack of links with other community members and families, which further marginalizes them and increases their susceptibility to harmful events which was also found by Al Amin et al., 2024 in one of their studies conducted on the impact of decadal riverbank erosion on the local livelihood. This comprehensive perspective underlines the necessity to recognize these social dynamics and societal constraints when resolving the vulnerabilities of FHHs, as their specific obstacles demand specific measures to strengthen their capacity for adaptation (Aktar et al., 2021).

The studied areas have long experienced multifaceted vulnerabilities to flooding. Despite annual efforts by government and support agencies in disaster preparedness and relief activities, these measures have not achieved the anticipated benefits, mostly due to insufficient vulnerability assessment methodology. It is vital that policymakers and practitioners integrate characteristics of

households, particularly headship, within their vulnerability evaluations (De Brito et al., 2018; Yang et al., 2018). A notable finding of this study is the increased flood-related vulnerability of female-headed households (FHHs) when compared with male-headed households (MHHs) along all aspects of vulnerability—social, physical, economic, and environmental. However, the differential between MHHs and FHHs is more prominent in the social and physical dimensions, while the gap is narrower in the economic and environmental elements. The failure to appropriately analyze and address these vulnerabilities underlines the need for more nuanced and headship-sensitive approaches in catastrophe preparation and intervention (Nguyen & Van Nguyen, 2019; Feloni et al., 2020). By analyzing and incorporating these unequal vulnerabilities, more effective and fair disaster management plans may be established, ensuring that the unique challenges faced by FHHs are effectively addressed. This method corresponds with broader research that emphasizes the necessity of incorporating household headship in vulnerability studies to promote more resilient and inclusive communities (Phung et al., 2016; Rana and Routray, 2018).

Intra-household choice-making dynamic play a critical role in disaster vulnerability, with female heads of families experiencing larger restraints relative compared to their male counterparts. These limits restrict their capacity to seek aid from others, as they often cannot reciprocate such support (Rahman, 2012). This unequal access to social resources and opportunities contributes considerably to the persisting gaps in vulnerability. This enhanced vulnerability is especially noticeable in the social and physical dimensions reflecting the broader structural and societal injustices that disadvantage FHHs. Addressing these inequities needs a full understanding of the intra-household power dynamics and social restrictions that unfairly drawbacks female heads. By integrating these findings into disaster preparedness and resilience-building initiatives, more fair and effective interventions can be devised, thereby reducing the multifaceted vulnerabilities of FHHs (Menoni et al., 2012; Islam & Hasan, 2023).

The involvement of individuals in various activities has a crucial role in determining the level of vulnerability experienced by both males and females in times of disasters (Rahman, 2012; Naz et al., 2018). Besides, engaging the community actively promotes a feeling of belonging and provides individuals with crucial disaster preparedness skills, hence decreasing vulnerability to negative consequences (Rayhan, 2010). Moreover, the level of confidence that families have in the effectiveness of governmental and social agencies in handling disasters significantly affects how vulnerable they feel. According to Al Amin et al., (2024), households with higher educational levels exhibit greater confidence by engaging in thorough planning and successfully carrying out their plans. This study substantiates prior research (Balica, 2009; Rahman, 2012; Birkmann, 2013; Defossez et al., 2017; Naz et al., 2018), illustrating that individuals with higher educational attainment possess superior capabilities in mitigating vulnerability to damage by leveraging their knowledge, such as promptly responding to early warnings. These findings underscore the critical importance of educational initiatives and active community engagement in bolstering disaster resilience. The enhanced capacity for informed decision-making and proactive measures among educated individuals highlights the pivotal role of education in fostering a resilient and well-prepared populace (Kamanga et al., 2020). Consequently, educated household heads exhibit heightened analytical capabilities, enabling them to manage their households more effectively. Key informants in this study also highlighted the notably low levels of female participation in various community activities, suggesting a need to reassess the selection processes to ensure meaningful and balanced participation. This reevaluation is essential for fostering an inclusive environment that leverages the potential contributions of all community members.



**Figure 9.** How flood causes different levels of vulnerability in the study area.

Approximately 90% of male spouses in female-headed households (FHHs) migrate for financial reasons, with 61% seeking opportunities abroad and 29% domestically. Predominantly engaged in low-wage, informal work, their income often falls short of satisfying all household needs, prioritizing important physical maintenance tasks such as home repairs, irrigation, and securing drinking water. Interestingly, the study found that FHHs tended to have better wages due to remittances. However, these money are mostly utilized to repaying loans and meeting everyday living expenditures. Despite this cash influx, FHHs lack decision-making capacity over income allotment and do not prioritize physical activities for preparedness for disasters. In regards to income, FHHs fare more well than male-headed families (MHHs). However, due to increased expenses, their savings are much lower, rendering them more fiscally vulnerable than MHHs. This economic vulnerability underlines the importance for focused interventions that address the unique financial problems encountered by FHHs and strengthen their capacity for disaster preparedness (Islam et al., 2013).

#### 4. CONCLUSION

The results of this study clarify the contrasting experiences of vulnerability to flooding among houses led by men (MHHs) and households led by women (FHHs). The research highlights the importance of taking into account a wide range of characteristics, including social, physical,

economic, and environmental aspects, when using gender-based models to estimate vulnerability to disasters. The study employs a strong approach to assess the overall vulnerability of male-headed households (MHHs) and female-headed households (FHHs) by considering the gender aspects of leadership and their relationship to flood risk. This methodology is especially beneficial for rural areas in Bangladesh, since it allows for the categorization of vulnerable populations into clear groups (very high, high, moderate, and low) and identifies the precise causes and variables that contribute to their vulnerability. By providing specific values for each indicator and dimension, and applying index ranking, this methodology equips planners and policymakers with the skills to detect differences between MHHs and FHHs, addressing the basic reasons that perpetuate vulnerability. Unlike broad vulnerability assessments, this nuanced approach reveals the differential flood vulnerability between MHHs and FHHs, hence enabling the implementation of customized, gender-inclusive interventions in disaster risk reduction (DRR) initiatives.

Furthermore, this research may facilitate the formulation and implementation of a gender-sensitive policy aimed at providing institutional support for Female-Headed Households (FHHs) to enhance women's access to governmental services, including banking and healthcare. For instance, improving access to financial loans, vocational training, essential infrastructural support, potable water supply, and effective communication systems would significantly alleviate vulnerabilities. The government should devise a strategy for infrastructure enhancement and maintenance to mitigate the impact of flood-related risks. Further capacity building can be achieved through subsidized educational and healthcare initiatives. It is imperative to elevate the literacy levels within flood-prone communities to empower them to enhance their readiness through comprehensive preparedness strategies. Residents in flood-affected regions are cognizant of their susceptibility to risks; however, empowerment is essential for self-protection and preparedness, enabling their active involvement in governmental preparedness programs.

Despite its strengths, the study also has several limitations. First, the analysis is geographically confined to Sirajganj Sadar Upazila, which may limit the generalizability of the findings to other flood-prone regions of Bangladesh or beyond. Second, the data were primarily based on self-reported information from households, which could be affected by biases such as underreporting or misreporting due to memory recall or social desirability. Third, while the index-based approach provides a structured and comparative understanding of vulnerability, it may oversimplify complex, dynamic, and context-specific interactions among the indicators. In addition, the study does not account for seasonal variability or the long-term changes in flood patterns that could influence vulnerability over time. Lastly, the study focuses primarily on binary gender classifications (MHHs vs. FHHs) and does not consider intra-household dynamics, intersectional identities, or gender-diverse populations, which may offer a more holistic understanding of vulnerability.

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## REFERENCES

- Aboul, Fazal, Younus. (2014). Floods in Bangladesh: Nature, History, Research, Causes and Types. doi: 10.1007/978-94-007-5494-2\_3
- Adam-Bradford, A., McGregor, D., & Simon, D. (2012). Community-based waste management strategies: peri-urban interface, Kumasi, Ghana. In *The Peri-Urban Interface* (pp. 251-265). Routledge.
- Agrawal, A. (2003). Sustainable governance of common-pool resources: context, methods, and politics. *Annual review of anthropology*, 32(1), 243-262.
- Airen, Aktar., Kanij, Shohani., Nazmul, Hasan., Kamrul, Hasan. (2021). (2) Flood Vulnerability Assessment by Flood Vulnerability Index (FVI) Method: A Study on Sirajganj Sadar Upazila. doi: 10.18485/IJDRM.2021.3.1.1
- Aktar, M. A., Shohani, K., Hasan, M. N., & Hasan, M. K. (2021). Flood vulnerability assessment by flood vulnerability index (FVI) method: a study on Sirajganj Sadar Upazila. *International Journal of Disaster Risk Management*, 3(1), 1-14.
- Aktar, M. A., Shohani, K., Hasan, M. N., & Hasan, M. K. (2021). Flood vulnerability assessment by flood vulnerability index (FVI) method: a study on Sirajganj Sadar Upazila. *International Journal of Disaster Risk Management*, 3(1), 1-14.
- Al Amin, S., Hossain, R. B., & Hasan, M. I. (2024). Decadal dynamics of Jamuna Riverbank erosion and its impact on local livelihoods in Shariakandi, Bangladesh. *Acadlore Trans. Geosci*, 3(1), 46-61.
- Armaş, I. (2012). Multi-criteria vulnerability analysis to earthquake hazard of Bucharest, Romania. *Natural hazards*, 63, 1129-1156.
- Balica, S. F., Douben, N., & Wright, N. G. (2009). Flood vulnerability indices at varying spatial scales. *Water science and Technology*, 60(10), 2571-2580.
- Balica, S., & Wright, N. G. (2010). Reducing the complexity of the flood vulnerability index. *Environmental hazards*, 9(4), 321-339.
- Balica, S.F.; Douben, N.; Wright, N.G. Flood vulnerability indices at varying spatial scales. *Water Sci. Technol.* 2009, 60, 2571–2580.
- Bari, F. Gender, disaster, and empowerment: A case study from Pakistan. In *The Gendered Terrain of Disaster: Through Women's Eyes*; Praeger: Westport, CO, USA, 1998; pp. 1–8.
- Bhuiyan, S. R., & Baky, A. A. (2014). Digital elevation based flood hazard and vulnerability study at various return periods in Sirajganj Sadar Upazila, Bangladesh. *International Journal of Disaster Risk Reduction*, 10, 48–58. <https://doi.org/10.1016/j.ijdr.2014.06.001>
- Birkmann, J., Cardona, O. D., Carreño, M. L., Barbat, A. H., Pelling, M., Schneiderbauer, S., & Welle, T. (2013). Framing vulnerability, risk and societal responses: the MOVE framework. *Natural hazards*, 67, 193-211.
- Birkmann, J.; Cardona, O.D.; Carreño, M.L.; Barbat, A.H.; Pelling, M.; Schneiderbauer, S.; Kienberger, S.; Keiler, M.; Alexander, D.; Zeil, P.; et al. Framing vulnerability, risk and societal responses: The MOVE framework. *Nat. Hazards* 2013, 67, 193–211.
- Blaikie, P., Cannon, T., Davis, I., & Wisner, B. (2014). *At risk: natural hazards, people's vulnerability and disasters*. Routledge.



- Briceno, S. (2002, March 6). Gender Mainstreaming in Disaster Reduction Panel. Commission on the Status of Women. New York Secretariat of the International Strategy for Disaster Reduction. Geneva: UN/ISDR. [www.unisdr.org](http://www.unisdr.org).
- Browne, M. J., & Hoyt, R. E. (2000). The demand for flood insurance: empirical evidence. *Journal of risk and uncertainty*, 20, 291-306.
- Chant, S. H. (2007). *Gender, generation and poverty: exploring the feminisation of poverty in Africa, Asia and Latin America*. Edward Elgar Publishing.
- Corbett J (1989) Poverty and sickness: the high costs of ill-health. *IDS Bull* 20(2):58–62
- Creswell, J.W. An expanded typology for classifying mixed methods research into designs. In *Handbook of Mixed Methods in Social and Behavioral Research*; Tashakkoriy, A., Teddlie, C., Eds.; Sage: Newcastle upon Tyne, UK, 2003; pp. 209–240.
- Cutter SL, Boruff BJ, Shirley WL (2003) Social vulnerability to environmental hazards. *Soc Sci Q* 84(2):242–261.
- Cutter, S. L. (1993). *Living with risk: the geography of technological hazards*. (No Title).
- Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2012). Social vulnerability to environmental hazards. In *Hazards vulnerability and environmental justice* (pp. 143-160). Routledge.
- Dankelman I, Jansen W (2012) Gender, environment and climate change: understanding the linkages. In: *Gender and climate change: an introduction*, Routledge, pp 49–82
- Dankelman, I. (2002). Climate change: Learning from gender analysis and women's experiences of organising for sustainable development. *Gender & Development*, 10(2), 21-29.
- Dankelman, I., & Fansen, W. (2012). Gender, environment and climate change: understanding the linkages. In *Gender and climate change: An introduction* (pp. 21-54). Routledge.
- Davison J (1988) *Women and the land: the african experience—Westview special studies on Africa, agriculture*. Westview Press, Boulder.
- De Brito, M. M., Evers, M., & Almoradie, A. D. S. (2018). Participatory flood vulnerability assessment: a multi-criteria approach. *Hydrology and Earth System Sciences*, 22(1), 373-390.
- Defossez, S., Vinet, F., & Leone, F. (2017). Assessing vulnerability to flooding: Progress and limitations. In *Floods* (pp. 241-257). Elsevier.
- Denton F (2001) Climate change, gender and poverty—academic babble or realpolitik? *Point de Vue* 14:1–2
- Deressa TT, Ringler C, Hassan RM (2010) Factors affecting the choices of coping strategies for climate extremes. The case of farmers in the Nile Basin of Ethiopia IFPRI Discussion Paper, 1032
- Dewan, A.M., Makoto, Nishigaki., Mitsuru, Komatsu. (2003). *Floods in Bangladesh: A Comparative Hydrological Investigation on Two Catastrophic Events*.
- Dhungel, R.; Ojha, R.N. Women's empowerment for disaster risk reduction and emergency response in Nepal. *Gend. Dev.* 2012, 20, 309–321
- Enarson E (2005) *Making risky environments safer: women building sustainable and disaster resilient communities*. New York: Published by the United Nations Divisions on Advancement of Women. <https://www.un.org/womenwatch/daw/>

[://www.academia.edu/6617414/Making\\_risky\\_environments\\_safer\\_Women\\_building\\_sustainable\\_and\\_disaster\\_resilient\\_communities](http://www.academia.edu/6617414/Making_risky_environments_safer_Women_building_sustainable_and_disaster_resilient_communities).

- Enarson, E. (2000, May). Gender issues in natural disasters: Talking points and research needs. In ILO InFocus Programme on Crisis Response and Reconstruction Workshop, Geneva (pp. 3-5).
- Enarson, E.; Chakrabarti, P.D. Women, Gender and Disaster: Global Issues and Initiatives; SAGE Publications: New Delhi, India, 2009.
- Ezemonye, M.N. Flood and female headed households in Illah rural community of Delta state, Nigeria. Acad. J. Interdiscip. Stud. 2015, 4, 109.
- Feloni, E., Mousadis, I., & Baltas, E. (2020). Flood vulnerability assessment using a GIS-based multi-criteria approach—The case of Attica region. Journal of Flood Risk Management, 13, e12563.
- Ferreira, S., 2011. Nature, socio-economics and flood-mortality. In: Proceedings of the 2011 Georgia Water Resources Conference. University of Georgia, Athens, Georgia. April 11–13.
- Flanagan, B. E., Gregory, E. W., Hallsiey, E. J., Heitgerd, J. L., & Lewis, B. (2011). A social vulnerability index for disaster management. Journal of homeland security and emergency management, 8(1), 0000102202154773551792.
- Fothergill, A.; Squier, E. Women and children in the 2015 earthquake in Nepal. In Living under the Threat of Earthquakes; Springer: Berlin/Heidelberg, Germany, 2018; pp. 253–271.
- Fuchs, S.; Birkmann, J.; Glade, T. Vulnerability assessment in natural hazard and risk analysis: Current approaches and future challenges. Nat. Hazards 2012, 64, 1969–1975.
- Gazi, Md., Khalil. (1990). Floods in Bangladesh: A question of disciplining the rivers. Natural Hazards, doi: 10.1007/BF00124395
- Ginige, K.; Amaratunga, D.; Haigh, R. Tackling women’s vulnerabilities through integrating a gender perspective into disaster risk reduction in the built environment. Procedia Econ. Financ. 2014, 18, 327–335
- Gokhale, V. Role of women in disaster management: An analytical study with reference to Indian society. In Proceedings of the 14th World Conference on Earthquake Engineering October, Beijing, China, 12 October 2008.
- Guddo. (2023). Conceptualization of Flooding Disaster: A Theoretical Perspective of Management. Disaster Advances, doi: 10.25303/172da040045.
- Hahn MB, Riederer AM, Foster SO (2009) The livelihood vulnerability index: a pragmatic approach to assessing risks from climate variability and change—a case study in Mozambique. Glob Environ Change 19(1):74–88
- Hallegatte, S.; Green, C.; Nicholls, R.J.; Corfee-Mrolot, J. Future flood losses in major coastal cities. Nat. Clim. Chang. 2013, 3, 802.
- Higaki, D., & Sato, G. (2012). Erosion and sedimentation caused by glacial lake outburst floods in the Nepal and Bhutan Himalayas. Global Environmental Research, 16(1), 71-76.
- Hilde, Orderud., Juho, Härkönen., Cathrine, Tranberg, Hårsaker., Malin, Bogren. (2022). Floods and maternal healthcare utilisation in Bangladesh. Population and Environment, doi: 10.1007/s11111-022-00410-3

- Holand, I. S., Lujala, P., & Rød, J. K. (2011). Social vulnerability assessment for Norway: A quantitative approach. *Norsk Geografisk Tidsskrift-Norwegian Journal of Geography*, 65(1), 1-17.
- IPCC (2007). Climate change 2007: impacts, adaptation and vulnerability. In: Parry ML, Canziani OF, Palutikof JP, van der Linden PJ, Hanson CE (eds) Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 976
- Islam MN, Islam MZ, Fujita K (2011) Coping with flood disaster: household level responses by the chardwellers on the river Padma in Bangladesh. *Indian J Power River Valley Dev* 61(9):159-171
- Islam, M. J., & Hasan, M. K. (2023). Understanding Flood Vulnerability Using Index-based Approach: A Study of Chilmari Upazila, Kurigram, Bangladesh. *Environment and Urbanization ASIA*, 14(2), 218-232.
- Islam, M. N., Malak, M. A., & Islam, M. N. (2013). Community-based disaster risk and vulnerability models of a coastal municipality in Bangladesh. *Natural hazards*, 69, 2083-2103.
- Jerin, T., Azad, M. A. K., & Khan, M. N. (2023). Climate change-triggered vulnerability assessment of the flood-prone communities in Bangladesh: A gender perspective. *International journal of disaster risk reduction*, 95, 103851.
- Jerin, T., Azad, M. A. K., & Khan, M. N. (2023). Climate change-triggered vulnerability assessment of the flood-prone communities in Bangladesh: A gender perspective. *International journal of disaster risk reduction*, 95, 103851.
- Jonkman, S. N., & Kelman, I. (2005). An analysis of the causes and circumstances of flood disaster deaths. *Disasters*, 29(1), 75-97.
- Kamanga, T. F., Tantanee, S., Mwale, F. D., & Buranajarukorn, P. (2020). A multi hazard perspective in flood and drought vulnerability: Case study of Malawi. *Geographia Technica*, 15(1), 132-142.
- Kaźmierczak, A., & Cavan, G. (2011). Surface water flooding risk to urban communities: Analysis of vulnerability, hazard and exposure. *Landscape and urban planning*, 103(2), 185-197.
- Khan, S. (2012). Vulnerability assessments and their planning implications: a case study of the Hutt Valley, New Zealand. *Natural Hazards*, 64, 1587-1607.
- Leya, R. S., Saha, D., Bala, S. K., & Huq, H. (2020). Gender vulnerability assessment due to flood in northern part of Bangladesh (a case study on 2017 flood). In *Water, flood management and water security under a changing climate: Proceedings from the 7th International Conference on Water and Flood Management* (pp. 235-249). Springer International Publishing.
- Lindell, M. K., & Prater, C. S. (2003). Assessing community impacts of natural disasters. *Natural hazards review*, 4(4), 176-185
- López-Martínez F, Gil-Guirado S, Pérez-Morales A (2017) Who can you trust? Implications of institutional vulnerability in flood exposure along the Spanish Mediterranean Coast. *Environ Sci Policy* 76:29-39
- Luna, K. C., & Hilhorst, D. (2022). Gendered experience of disaster: Women's account of evacuation, relief and recovery in Nepal. *International Journal of Disaster Risk Reduction*, 72, 102840.

- Mavhura E, Manyena B, Collins AE (2017) An approach for measuring social vulnerability in context: the case of flood hazards in Muzarabani district, Zimbabwe. *Geoforum* 86(September):103–117. <https://doi.org/10.1016/j.geoforum.2017.09.008>
- Mazumdar, J., & Paul, S. K. (2016). Socioeconomic and infrastructural vulnerability indices for cyclones in the eastern coastal states of India. *Natural Hazards*, 82, 1621-1643.
- Mehta, M. (2007). *Gender matters: Lessons for disaster risk reduction in South Asia*. International Center for Integrated Mountain Development, Kathmandu, Nepal.
- Menoni, S., Molinari, D., Parker, D., Ballio, F., & Tapsell, S. (2012). Assessing multifaceted vulnerability and resilience in order to design risk-mitigation strategies. *Natural hazards*, 64, 2057-2082.
- Mitchell, J. K. (Ed.). (1999). *Crucibles of hazard: mega-cities and disasters in transition* (p. 535). Tokyo: United Nations University Press.
- Naz F (2019) Gender based analysis of vulnerability and adaptability to flood: the case of char-farming households in Bangladesh. PhD, Doctoral Dissertation Asian Institute of Technology, Thailand
- Naz F, Doneys P, Saqib SE (2018) Adaptation strategies to floods: a gender-based analysis of the farming-dependent char community in the Padma floodplain, Bangladesh. *Int J Disaster Risk Reduct* 28(2018):519–530
- Nguyen, C. T., & Van Nguyen, B. (2019). Application of flood vulnerability index in flood vulnerability assessment: a case study in Mai Hoa Commune, Tuyen Hoa District, Quang Binh Province. *Sustainable Water Resources Management*, 5(4), 1917-1927.
- Nhuan, M. T., Tue, N. T., Hue, N. T. H., Quy, T. D., & Lieu, T. M. (2016). An indicator-based approach to quantifying the adaptive capacity of urban households: The case of Da Nang city, Central Vietnam. *Urban Climate*, 15, 60-69.
- Panthi, J., Aryal, S., Dahal, P., Bhandari, P., Krakauer, N. Y., & Pandey, V. P. (2016). Livelihood vulnerability approach to assessing climate change impacts on mixed agro-livestock smallholders around the Gandaki River Basin in Nepal. *Regional environmental change*, 16, 1121-1132.
- Papathoma-Köhle M, Gems B, Sturm M, Fuchs S (2017) Matrices, curves and indicators: a review of approaches to assess physical vulnerability to debris flows. *Earth Sci Rev* 171:272–288
- Phung, D.; Rutherford, S.; Dwirahmadi, F.; Chu, C.; Do, C.M.; Nguyen, T.; Duong, N.C. The spatial distribution of vulnerability to the health impacts of flooding in the Mekong Delta, Vietnam. *Int. J. Biometeorol.* 2016, 60, 857–865
- Phung, D.; Rutherford, S.; Dwirahmadi, F.; Chu, C.; Do, C.M.; Nguyen, T.; Duong, N.C. The spatial distribution of vulnerability to the health impacts of flooding in the Mekong Delta, Vietnam. *Int. J. Biometeorol.* 2016, 60, 857–865
- Polsky, C.; Neff, R.; Yarnal, B. Building comparable global change vulnerability assessments: The vulnerability scoping diagram. *Glob. Environ. Chang.* 2007, 17, 472–485
- Rahman, S. (2011). *Households' flood vulnerability assessment in context of climate change* (Master's thesis, University of Twente).
- Rakib, M. A., Islam, S., Nikolaos, I., Bodrud-Doza, M., & Bhuiyan, M. A. (2017). Flood vulnerability, local perception and gender role judgment using multivariate analysis: A

- problem-based “participatory action to Future Skill Management” to cope with flood impacts. *Weather and climate extremes*, 18, 29-43.
- Rana IA, Routray JK (2018) Multidimensional model for vulnerability assessment of urban flooding: an empirical study in Pakistan. *Int J Disaster Risk Sci* 9(3):359–375. <https://doi.org/10.1007/s13753-018-0179-4>
- Rana, I. A., & Routray, J. K. (2018). Integrated methodology for flood risk assessment and application in urban communities of Pakistan. *Natural Hazards*, 91, 239-266.
- Rasch, R. J. (2016). Assessing urban vulnerability to flood hazard in Brazilian municipalities. *Environment and urbanization*, 28(1), 145-168.
- Rayhan, M. I. (2010). Assessing poverty, risk and vulnerability: a study on flooded households in rural Bangladesh. *Journal of Flood Risk Management*, 3(1), 18-24.
- Rehima M, Belay K, Dawit A, Rashid S (2013) Factors affecting farmers’ crops diversification: evidence from SNNPR, Ethiopia. *Int J Agric Sci* 3(6):558–565.
- Saqib SE, Ahmad MM, Panezai S, Ali U (2016) Factors influencing farmers’ adoption of agricultural credit as a risk management strategy: the case of Pakistan. *Int J Disaster Risk Reduct* 17(2016):67–76
- Schröter, D.; Polsky, C.; Patt, A.G. Assessing vulnerabilities to the effects of global change: An eight step approach. *Mitig. Adapt. Strateg. Glob. Chang.* 2005, 10, 573–595.
- Sebastiaan, N., Jonkman, A., Curran, M., Laurens, M., Bouwer. (2024). Floods have become less deadly: an analysis of global flood fatalities 1975–2022. *Natural Hazards*, doi: 10.1007/s11069-024-06444-0.
- Shah AA, Ye J, Abid M, Khan J, Amir SM (2018) Flood hazards: household vulnerability and resilience in disaster-prone districts of Khyber Pakhtunkhwa province, Pakistan. *Natu Hazards* 93(1):147–165. <https://doi.org/10.1007/s11069-018-3293-0>
- Smit B, Pilifosova O (2003) From adaptation to adaptive capacity and vulnerability reduction. In: *Climate change, adaptive capacity and development*, World Scientific, pp 9–28
- Suryanto S, Rahman A (2019) Application of livelihood vulnerability index to assess risks for farmers in the Sukoharjo Regency and Klaten Regency, Indonesia, Jambá. *J Disaster Risk Stud* 11(1):1–9. <https://doi.org/10.4102/jamba.v11i1.739>
- Taubenböck, H., Post, J., Roth, A., Zosseder, K., Strunz, G., & Dech, S. (2008). A conceptual vulnerability and risk framework as outline to identify capabilities of remote sensing. *Natural Hazards and Earth System Sciences*, 8(3), 409-420.
- Thouret J, Ettinger S, Guitton M, Santoni O, Magill C, Martelli K, Zuccaro G, Revilla V, Charca JA, Arguedas A (2014) Assessing physical vulnerability in large cities exposed to flash floods and debris flows: the case of Arequipa (Peru). *Nat Hazards* 73(3):1771–1815
- Thouret, J. C., Ettinger, S., Guitton, M., Santoni, O., Magill, C., Martelli, K., ... & Arguedas, A. (2014). Assessing physical vulnerability in large cities exposed to flash floods and debris flows: the case of Arequipa (Peru). *Natural Hazards*, 73, 1771-1815.
- UNISDR. *Living with Risk, A Global Review of Disaster Reduction Initiatives 2004 Version*; UNISDR: Geneva, Switzerland, 2004; Volume 1, pp. 41–42.
- Van Dijkhorst, H., & Vonhof, S. (2005). *Gender and humanitarian aid: a literature review of policy and practice*. Disaster Studies Wageningen University.

- Van Dijkhorst, H.; Vonhof, S. *Gender and Humanitarian Aid: A Literature Review of Policy and Practice*; Disaster Studies; Wageningen University: Wageningen, The Netherlands, 2005.
- Weis SWM, Agostini VN, Roth LM, Gilmer B, Schill SR, Knowles JE, Blyther R (2016) Assessing vulnerability: an integrated approach for mapping adaptive capacity, sensitivity, and exposure. *Clim Change* 136(3–4):615–629
- Welle T, Depietri Y, Angignard M, Birkmann J, Renaud F, Greiving S (2014) Vulnerability assessment to heat waves, floods, and earthquakes using the move framework: test case Cologne, Germany. In: Birkmann J, Kienberger S, Alexander DE (eds) *Assessment of vulnerability to natural hazards*. Elsevier, Bonn, pp 91–124
- Willroth P, Diez JR, Arunotai N (2011) Modelling the economic vulnerability of households in the Phang-Nga Province (Thailand) to natural disasters. *Nat Hazards* 58(2):753–769
- Wisner B, Blaikie P, Cannon T, Davis I (2004) *At risk: Natural hazards, people's vulnerability and disasters*, 2nd edn. Routledge, London
- Yamane, T. *An Introductory Analysis of Statistics*; Harper and Row: New York, NY, USA, 1967.
- Yang, W., Xu, K., Lian, J., Bin, L., & Ma, C. (2018). Multiple flood vulnerability assessment approach based on fuzzy comprehensive evaluation method and coordinated development degree model. *Journal of environmental management*, 213, 440-450.
- Yoon DK (2012) Assessment of social vulnerability to natural disasters: a comparative study. *Nat Hazards* 63(2):823–843
- Yoon, D. K. (2012). Assessment of social vulnerability to natural disasters: a comparative study. *Natural hazards*, 63, 823-843.
- Yu, Duan. (2024). Global projections of flood risk under climate change. doi: 10.5194/egusphere-egu24-7030.
- Zhou, Y.; Liu, Y.; Wu, W.; Li, N. Integrated risk assessment of multi-hazards in China. *Nat. Hazards* 2015, 78, 257–280