ASSESSMENT OF FLASH FLOOD VULNERABILITY AND ITS DRIVERS IN A COASTAL DISTRICT OF BANGLADESH: AN INTEGRATED APPROACH FOR ENHANCING FLOOD RESILIENCE

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CERTIFICATION

The thesis report titled "Assessment of Flash Flood Vulnerability and Its Drivers in A Coastal District of Bangladesh: An Integrated Approach for Enhancing Flood Resilience" submitted by Sajib Sarker, Student ID. No. 22MURP001, Session: 2022-2023 has been accepted as satisfactory in partial fulfilment of the requirements for the degree of Master of Urban and Regional Planning by Course and Thesis on 27st August, 2025.

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Dedication

Dedicated to my beloved parents, whose unwavering support has shaped my journey, and to the Almighty God, for his endless grace and guidance.

List of Publications

Journal Article

- Sarker, S., Jahan, I., Wang, X., & Azad, A. (2025). *Geospatial Approach to Assess Flash Flood Vulnerability in a Coastal District of Bangladesh: Integrating the Multifaceted Dimension of Vulnerabilities*. ISPRS International Journal of Geo-Information, 14(5), 194. https://doi.org/10.3390/ijgi14050194.
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Approval/Declaration by the Supervisor

This is to certify that Sajib Sarker has carried out this research work under my supervision, and that he has fulfilled the relevant Academic Ordinance of the Chittagong University of Engineering and Technology, so that he is qualified to submit the following Thesis in the application for the degree of MASTER of URBAN AND REGIONAL PLANNING by Course and Thesis. Furthermore, the Thesis complies with the PLAGIARISM and ACADEMIC INTEGRITY regulation of CUET.

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Abstract

Flash floods pose a significant threat to Bangladesh. To effectively mitigate the impacts of flash floods, it is essential to conduct a comprehensive flash flood vulnerability assessment, incorporating multiple triggering factors. This study aims to assess flash flood vulnerability in the Feni district through a unique approach, integrating multiple dimensions of vulnerability and to create recommendations for enhancing resilience, by examining the key drivers and assessing the effectiveness of current flood control practices. The study utilizes the vulnerability framework developed by UNESCO-IHE, where four dimensions (social, physical, economic, and environmental) of vulnerability were analysed. For each dimension, specific variables were selected to assess exposure, susceptibility, and resilience. The geospatial layers of influencing vulnerability factors were integrated together using the weights developed through PCA, to create flash flood vulnerability maps of four dimensions. Also, these were overlaid to generate a composite flash flood vulnerability map. Then to assess the drivers of this vulnerability, 384 respondents were chosen using Cochran's formula and stratified random sampling technique. After that a questionnaire survey was administered to obtain their opinions on 30 vulnerability drivers to assess the triggering factors. Then the existing framework gaps were covered by policy analysis. The analysis revealed a distinct spatial distribution of vulnerability across Feni District. In terms of environmental vulnerability, about 14% of the total area falls into the very highly vulnerable zone, whereas 13%, 8% and 5% of the study area found to be very highly vulnerable for social, economic and physical aspects respectively. The composite flash flood vulnerability map identified key vulnerability hotspots, with the most vulnerable unions being Feni Pourashava (68% very high), Sonagazi Paurashava (40% very high), and

Nawabpur (32% very high). In case of driver assessment an average survey scores ranged from 3.91 to 4.06, indicating significant vulnerability across all aspects. Social and economic vulnerabilities were particularly evident in dimensionality correlation assessment. Strong connections between the drivers were also found via analysis. Essential infrastructure problems had shown the highest overall score, making it the top priority as a vulnerability driver. Other top drivers are the lack of job opportunities, living in high-risk flood zones, lack of early warning systems, and high healthcare costs. Weak early warning systems, inadequate stakeholder coordination, and limited community inclusion were prominent among the policy deficiencies. A multifaceted framework for recommendations was put forth, focusing on interventions at the institutional, community, and structural levels. By offering a reproducible, empirically supported framework for vulnerability assessment and policy integration, this study emphasizes the necessity of comprehensive, community-based, and policy-responsive flood resilience plans in Bangladesh and other high-risk areas.

বিমূর্ত

ফ্ল্যাশ ফ্লাড (হঠাৎ বন্যা) বাংলাদেশের জন্য একটি গুরুত্বপূর্ণ হুমকি। ফ্ল্যাশ ফ্লাডের প্রভাব কার্যকরভাবে প্রশমিত করতে একাধিক ট্রিগারিং ফ্যাক্টর (সক্রিয়কারী উপাদান) অন্তর্ভুক্ত করে একটি সমন্বিত ফ্ল্যাশ ফ্লাড ঝুঁকি মূল্যায়ন করা অপরিহার্য। এই গবেষণার উদ্দেশ্য হলো ফেনী জেলায় ফ্ল্যাশ ফ্লাডের ঝুঁকি মূল্যায়ন করা, যেখানে ঝুঁকির বিভিন্ন দিক বিবেচনা করে স্থিতিস্থাপকতা বৃদ্ধির জন্য প্রমাণ-ভিত্তিক সুপারিশ তৈরি করা। এজন্য ফ্ল্যাশ ফ্লাডের মূল চালকগুলি বিশ্লেষণ এবং বর্তমান বন্যা নিয়ন্ত্রণ পদ্ধতির কার্যকারিতা মূল্যায়ন করা হয়েছে। এই গবেষণায় ইউনেস্কো-আইএইচই-এর বিকশিত ঝুঁকি কাঠামো ব্যবহার করা হয়েছে। ঝুঁকির চারটি দিক বিশ্লেষণ করা হয়েছেঃ সামাজিক, ভৌত, অর্থনৈতিক ও পরিবেশগত। প্রতিটি দিকের জন্য এক্সপোজার (সংস্পর্শ), সংবেদনশীলতা এবং স্থিতিস্থাপকতা মূল্যায়নের জন্য নির্দিষ্ট ভেরিয়েবল নির্বাচন করা হয়েছিল। এসব ভেরিয়েবলের ওয়েইট নির্ধারণে প্রিন্সিপাল কম্পোনেন্ট অ্যানালাইসিস (PCA) ব্যবহার করা হয়েছে। ভৌগোলিক তথ্যের স্তরগুলিকে একীভূত করে চারটি দিকের ফ্ল্যাশ ফ্লাড ঝুঁকি মানচিত্র তৈরি করা হয়েছে, যা পরবর্তীতে সমন্বিত ঝুঁকি মানচিত্রে রূপান্তরিত হয়েছে। ককরানের সূত্র অনুসারে স্তরভিত্তিক নমুনায়ন পদ্ধতিতে ৩৮৪ জন উত্তরদাতা নির্বাচন করে একটি প্রশ্নপত্রের মাধ্যমে ঝুঁকি নির্দেশক বিশ্লেষণে তাদের মতামত সংগ্রহ করা হয়। এতে ৩০টি ঝুঁকি নির্দেশক বিশ্লেষণ করা হয়েছে। নীতি বিশ্লেষণের মাধ্যমে বিদ্যমান কাঠামোগুলিও পর্যালোচনা করা হয়েছে। বিশ্লেষণে দেখা গেছে, ফেনী জেলায় ঝুঁকির একটি স্পষ্ট স্থানিক বণ্টন রয়েছে। পরিবেশগত ঝুঁকির ক্ষেত্রে মোট এলাকার প্রায় ১৪% অতি উচ্চ ঝুঁকিপূর্ণ অঞ্চল হিসেবে চিহ্নিত হয়েছে। অন্যদিকে, সামাজিক, অর্থনৈতিক ও ভৌত দিক থেকে যথাক্রমে ১৩%, ৮% ও ৫% এলাকা অতি উচ্চ ঝুঁকিতে রয়েছে। সমন্বিত ফ্ল্যাশ ফ্লাড ঝুঁকি মানচিত্রে প্রধান ঝুঁকিপূর্ণ হটস্পট হিসেবে শনাক্ত করা হয়েছে ফেনী পৌরসভা (৬৮% অতি উচ্চ ঝুঁকি), সোনাগাজী পৌরসভা (৪০% অতি উচ্চ ঝুঁকি) এবং নবাবপুর (৩২% অতি উচ্চ ঝুঁকি)। গড় জরিপ স্কোর ৩.৯১ থেকে ৪.০৬ পর্যন্ত ছিল, যা সকল দিকেই উল্লেখযোগ্য ঝুঁকি নির্দেশ করে। বিশেষত সামাজিক ও অর্থনৈতিক দুর্বলতা প্রকট ছিল। পারস্পরিক সম্পর্ক বিশ্লেষণের মাধ্যমে ঝুঁকির চালকগুলির মধ্যে শক্ত সংযোগ পাওয়া গেছে। দুর্বল প্রারম্ভিক সতর্কতা ব্যবস্থা, স্টেকহোল্ডারদের মধ্যে সমন্বয়ের অভাব এবং অংশগ্রহণের সীমাবদ্ধতা নীতি সংক্রান্ত ঘাটতিগুলোতে স্পষ্ট ছিল। সুপারিশ হিসেবে একটি বহুমুখী কাঠামো প্রস্তাব করা হয়েছে, যা প্রাতিষ্ঠানিক, সম্প্রদায়ভিত্তিক ও অবকাঠামোগত স্তরে হস্তক্ষেপের উপর দৃষ্টির প্রয়োজনীয়তা তুলে ধরে। এই গবেষণা বাংলাদেশ এবং অন্যান্য উচ্চ-ঝুঁকিপূর্ণ অঞ্চলের জন্য একটি বন্যা স্থিতিস্থাপকতা পরিকল্পনা এর প্রয়োজনীয়তা তুলে ধরে। এটি ঝুঁকি মূল্যায়ন এবং নীতি সমন্বয়ের জন্য একটি প্রমাণ-ভিত্তিক কাঠামো প্রদান করে।

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Nomenclature

FFVA	Flash Flood Vulnerability Assessment
PCA	Principal Component Analysis
GIS	Geographic Information System
RS	Remote Sensing
DEM	Digital Elevation Model
NDVI	Normalized Difference Vegetation Index
LULC	Land Use/Land Cover
DRR	Disaster Risk Reduction
CRA	Climate Risk Assessmen
SoVI	Social Vulnerability Index
EVI	Economic Vulnerability Index
FFWC	Flood Forecasting and Warning Centre
NASA	National Aeronautics and Space Administration
NetCDF	Network Common Data Form
UNDRR	United Nations Office for Disaster Risk Reduction
MCDM	Multi Criteria Decision Making
BMD	Bangladesh Meteorological Department
BWDB	Bangladesh Water Development Board

Chapter 1: INTRODUCTION

This chapter presents the study's overall context, goal, and scope, laying the groundwork for the study. It starts by providing background information, emphasizing the increasing risk of flash floods in Bangladesh's Feni area, which is influenced by a number of socioeconomic, environmental, and physical vulnerabilities. The purpose and particular objectives of the study are then stated, with an emphasis on the investigation of the underlying causes of flash flood vulnerability and the spatial assessment of that vulnerability. After that, research questions are introduced, which direct the investigation toward comprehending the socioeconomic processes and spatial patterns of flood vulnerability. Finally, it outlines the anticipated results, highlighting how the study seeks to produce useful information for improving flood resilience and guiding regional and national disaster risk management plans.

1.1 BACKGROUND OF THE STUDY

Flash floods have become among the most destructive natural catastrophes occurring globally, particularly in low-lying, flood-prone areas [1]. These sudden and intense floods result from excessive rainfall within a short timeframe, often overflows drainage systems, submerging extensive regions, and incurring significant socioeconomic and environmental harm [2].

It's one of the most devastating natural hazards affecting Bangladesh, a country known for its high susceptibility to climate-induced disasters due to its low-lying topography and high population density [3]. Flash floods present a special challenge among the various forms of flooding, because of its sudden onset, rapid advancement, and short response time [4]. In contrast to riverine or coastal floods, flash floods are usually caused by intense, short-duration rainfall events, which are frequently made worse by upstream rainfall from nearby areas [5]. Because of its suddenness, these events are especially damaging, taking an

immense impact on lives, livelihoods, infrastructure, and environmental resources [5].

The Feni district in southeast Bangladesh is frequently affected by flash floods, resulting in consistent disruption of livelihoods, infrastructure damage, and community displacement [6]. Socio-economic disparities, inadequate infrastructure, and ineffective policy implementation exacerbate the impacts of these floods, making vulnerability assessment an urgent field of study [7]. The increasing frequency and severity of flash floods, exacerbated by climate change, necessitate a comprehensive analysis of the factors contributing to vulnerability and the formulation of potential resilience strategies [8].

The degree to which a community, system, or asset is exposed to, prone to, and able to recover from the negative effects of a hazard is reflected in its vulnerability [9]. Flash flood vulnerability is a multi-dimensional phenomenon shaped by the interaction of social, physical, economic, and environmental factors [10]. Such as, households living in low-lying flood-prone areas with weak infrastructure systems are at greater risk than those living in elevated and structurally sound areas [11]. At the same time, economically marginal groups living under the pressures of resource inadequacies, health facilities, and access to early warning experiences high levels of vulnerability [12]. Therefore, a comprehensive assessment of flash flood vulnerability is much needed, considering these diverse dimensions to provide a holistic understanding of the problem [9], [11].

The findings of this study will contribute to the broader understanding of flood vulnerability assessment and resilience-building strategies in Bangladesh, and can have significant implications for policymakers, local government bodies, and disaster management authorities. By providing evidence-based insights into the drivers of flood vulnerability, the study will contribute to the formulation of more effective flood resilience strategies, which can be applied not only in Feni district but also in other flood-prone regions of Bangladesh. In the end, this

research seeks to improve communities' ability to adapt and lower the risks of flash floods, which will support the region's overall target of sustainable development.

1.2 GOAL

To assess the multidimensional flash flood vulnerability in Feni district and examine the drivers to provide recommendations for enhancing flood resilience.

1.3 OBJECTIVES

To achieve this goal, three specific objectives were formulated.

- To map and quantify physical, social, economic, environmental and composite aspect related to flash floods in Feni district.
- To analyse the key drivers of flash flood vulnerabilities for investigating the underlying mechanisms.
- To develop recommendations for enhancing flood resilience by integrating findings with the existing policy frameworks.

1.4 RESEARCH QUESTIONS

The study aims to answer three important research questions to achieve its research objectives for understanding the investigated subject matter.

- What is the spatial distribution of flash flood vulnerability across Feni district, Bangladesh, considering the interplay of physical, social, economic, and environmental factors, through the creation of a comprehensive geospatial vulnerability map?
- How do different stressors, such as social inequalities, economic disparities, and limited access to resources, act as drivers of flood vulnerability in Feni?
- To what extent are existing policies and infrastructure effective in mitigating flash flood vulnerability in identified hotspots within Feni district,

considering the unveiled drivers of vulnerability, and how can this knowledge be used to formulate data-driven recommendations for enhanced flood resilience?

1.5 SIGNIFICANCE AND RATIONALITY

This study is notable for its uniqueness and significance because it advances the traditional methods of vulnerability assessment in many notable ways. This study's unique contribution lies in the dynamic integration of geospatial technology with field investigation, the development of multi-dimensional vulnerability maps, and the clear focus on drivers and policy gaps of flash flood-specific vulnerability [13]. A comprehensive, multi-dimensional approach is used in this study to evaluate social, physical, economic, and environmental vulnerabilities in both singular and integrated way, in contrast to earlier research that frequently treats vulnerability dimensions in isolation [3], [5], [14]. Moreover, the study introduces a novel methodological framework for producing composite vulnerability maps, which not only visualize the spatial distribution of overall composite vulnerability but also identify areas of compounded risk of flash flood where multiple dimensions of vulnerability intersect. This intersectional approach enables a more precise identification of high-vulnerable zones, which is crucial for targeted disaster mitigation and response [15].

Additionally, while the use of Principal Component Analysis (PCA) is well-documented method, the study's application of PCA goes beyond mere dimensionality reduction by integrating it with geospatial analysis, thereby providing a data-driven approach to weight assignment. It makes it possible to more accurately determine the relative importance of each variable by reducing the dimensionality of the data while keeping the most important information [16]. This data-driven approach ensures that the final vulnerability maps accurately reflect the ground realities. By employing PCA, the study reduces the

bias that is frequently connected to manual weight assignment, which raises the analysis's credibility [16], [17]. Once the weights were determined, the geospatial layers corresponding to each vulnerability dimension were integrated to produce individual flash flood vulnerability maps for the four dimensions. These maps offer insight into how each dimension contributes to the overall flash flood vulnerability. Such as, areas with high social vulnerability may coincide with regions experiencing high physical vulnerability, indicating a compounded risk. The final stage of the geospatial analysis involved overlaying the four-dimensional maps to create a composite flash flood vulnerability map, offering a comprehensive view of the overall vulnerability. This integrated approach provides a more complete understanding of the spatial distribution of flash flood vulnerability and highlights priority areas for intervention [18]. This methodological fusion enhances the objectivity and accuracy of vulnerability mapping, making it a replicable approach for other disaster-prone regions. Collectively, these establish the study's novelty and underscore its contribution to the field of disaster risk management, particularly for regions facing flash flood hazards.

Also, earlier research on flash flood vulnerability mostly concentrated on hazard mapping and consequences related to climate change [19], [20]. Combined study on flash flood vulnerability driving forces and policy evaluation as well as adaptation techniques is lacking in Bangladesh [21]. Also lack of notable works on community-based disaster management, and the socio-economic impact of floods [22]. Recent floods in Feni in 2024 have also underlined the need of integrated flood management, and data driven solutions, and policy-driven measures to lower flood hazards. Furthermore, very few studies have thoroughly examined the multi-dimensional factors of flash flood vulnerability at the local level together with assessing policy efficacy [19], [23], [23].

Although many studies have looked at flood vulnerability and disaster risk management in Bangladesh, there is still a great void in localized, empirical

research looking at the multiple aspects of flash flood vulnerability in the Feni district [24], [25]. Moreover, current studies concentrate on macro-level policy analysis without giving enough thought to the on-ground reality of impacted populations [25]. The evaluation of how various vulnerability drivers interact with one another and how present regulations either reduce or increase these vulnerabilities also reveals another disparity [22]. This study hopes to fulfil these gaps by means of a field-based assessment and combining of research results with policy analysis to provide a more complex knowledge and recommendation measure for flash flood vulnerability.

Through filling in these knowledge gaps, this study expects to contribute both theoretical and realistic flood control measures. Policymakers, urban designers, disaster management officials, and local communities will find the results pertinent in developing more successful resilience-building projects. The way the study combines vulnerability drivers' assessment with policy analysis assurances that the results of the study are not only theoretical but also relevant for practical attempts at catastrophe risk reduction. Also, this work is significant since it could guide actual policy changes and disaster risk lowering strategies for Bangladesh. The research results will add a more complete knowledge of the multi- dynamics of flash floods, therefore enabling the development of focused solutions addressing the particular difficulties experienced by underprivileged areas [26].

1.6 EXPECTED OUTCOME

This study is expected to produce several significant results. First, it will offer an in-depth analysis of the multi-dimensional drivers of flash flood vulnerability in Feni district, offering valuable empirical data for policymakers and researchers. Second, the study will highlight the strengths and shortcomings of current flood control measures. Third, it will offer practical recommendations for enhancing community resilience, focusing on policy reforms, infrastructure

improvements, and community engagement. By linking the gap between research and policy, the study ultimately aspires to contribute to a more resilient future.

Moreover, this study is to reveal distinct spatial patterns of flash flood vulnerability. Certain areas which are consistently identified as high-risk zones across multiple dimensions, reflecting the need for targeted interventions in these locations. By identifying the regions with the highest composite vulnerability, disaster management authorities can prioritize resource allocation, enhance early warning systems, and develop community-based risk reduction strategies.

The findings of the research provide important new information on the underlying dynamics and geographic variability of flash flood vulnerability in the Feni District. The study offers a sophisticated knowledge of how many vulnerability indicators interact and appear across the landscape by using a multifaceted and spatially explicit approach. This information is essential for determining priority intervention areas and guiding the creation of risk mitigation plans tailored to the particular scenario. Additionally, the composite vulnerability map produced by this research are useful resources for disaster management organizations, urban planners, and local government decision-makers.

1.7 THESIS OUTLINE

This thesis is organized into six chapters to provide a comprehensive analysis of flash flood vulnerability and its underlying drivers in Feni district, Bangladesh. **Chapter 1** introduces the study by outlining the background, goals, objectives, research questions, significance, rationale, and expected outcomes, concluding with this outline. **Chapter 2** reviews relevant literature, including the concept and dimensions of vulnerability, various flood vulnerability assessment approaches, the context of flash floods in coastal Bangladesh, and both the conceptual and analytical frameworks used in this study. **Chapter 3** describes the

methodology, detailing the study area's profile, selection of variables for different vulnerability dimensions, data preprocessing, normalization, PCA-based weight generation, vulnerability assessment framework, sampling strategies, and techniques for identifying and analyzing the driving forces of vulnerability. **Chapter 4** presents the results, including spatial distribution and composite mapping of vulnerability, identification of hotspots, comparative analysis across dimensions, driver assessment, correlation analysis, evaluation of relevant national policies and institutional frameworks, identification of policy gaps, and formulation of recommendations to reduce vulnerabilities. **Chapter 5** provides a critical discussion of the findings, connects them with existing literature, explores their practical implications, acknowledges the limitations of the study, and suggests directions for future research. Finally, **Chapter 6** concludes the thesis by summarizing the key findings and providing an integrated reflection on how these insights can contribute to enhancing flood resilience and guiding evidence-based policy and planning interventions.

Chapter 2: LITERATURE REVIEW

This chapter presents the theoretical framework that underpins the assessment of flash flood vulnerability and its drivers. It establishes the conceptual basis for the study by discussing the definitions and dimensions of vulnerability, reviewing relevant assessment approaches, and outlining the analytical lens through which the research questions are addressed. The framework combines geospatial analysis, vulnerability theory, and flood vulnerability concepts to support the evaluation of spatial disparities and systemic drivers of flood vulnerability in Feni. Ultimately, this chapter guides the methodological design and provides the intellectual support for interpreting findings and generating actionable insights for enhancing flood resilience.

2.1 CONCEPT OF VULNERABILITY

In the context of natural hazards, vulnerability is the degree to which a system, community, or individual is likely to suffer harm as a result of being exposed to a hazard, given its inherent susceptibility and ability to adapt or recover [27]. It is generally considered to be a multifaceted concept with elements of the physical, social, economic, and environmental domains [28]. Vulnerability is defined by the Intergovernmental Panel on Climate Change (IPCC) as the tendency or predisposition to be negatively impacted, encompassing both sensitivity to harm and the inability to cope and adapt [29]. Vulnerability is frequently framed in disaster risk science as a function of three factors: resilience, susceptibility, and exposure. Susceptibility measures the chance of getting hurt because of vulnerability or lack of protection; resilience measures the capacity to foresee, absorb, react to, and recover from the effects of hazards; and exposure measures the presence of people, assets, and systems in hazard-prone areas [30].

Because there is little time for warning and response, vulnerability is especially severe in the particular context of flash floods, which are sudden, short

duration floods brought on by heavy rainfall and rapid runoff. Understanding the spatial and structural manifestations of vulnerability requires acknowledging that it is a result of both biophysical exposure and socioeconomic circumstances. This understanding is essential for determining vulnerability hotspots, examining underlying causes, and creating focused resilience-building plans [31].

2.2 FLOOD VULNERABILITY ASSESSMENT APPROACHES

From basic hazard-exposure models to more complex, multifaceted methods that incorporate institutional, social, and spatial factors, flood vulnerability assessment has changed over time. To map and measure vulnerability to flooding, a number of frameworks and methodologies have been developed; these vary in complexity, scope, and scale [32]. Composite vulnerability indices, indicator-based evaluations, and GIS-based spatial analyses are some of the most popular. Indicator-based methods use measurable factors as variables for vulnerability dimensions [28], [31], [33]. To create composite indices that represent relative vulnerability across regions, these indicators are frequently combined using weighting techniques like Principal Component Analysis (PCA) or the Analytical Hierarchy Process (AHP) [34].

Composite flood vulnerability mapping, particularly when integrated with geospatial technologies, allows for the visualization of spatial patterns and identification of high-vulnerable zones. GIS facilitates the overlay of multiple data layers enabling a holistic and location-specific understanding of vulnerability [31]. This spatial approach is especially useful in flood-prone regions like Feni, where natural and human systems interact dynamically. Recent studies also emphasize the importance of integrating socio-political factors and adaptive capacities into vulnerability assessments to move beyond static measurements and reflect real-world complexities [29], [30], [35], [36].

A hybrid approach that combines geospatial analysis, composite mapping, and indicator-based assessment has been chosen for this study. This makes it possible to create a thorough vulnerability profile by combining several datasets. The strategy is also adapted to the particular geographic and sociopolitical circumstances of the Feni area and aligns with global frameworks like the IPCC and the UNESCO-IHE model [37]. This methodological orientation forms the backbone of the analytical framework developed in subsequent chapters.

2.3 FLASH FLOODS IN COASTAL BANGLADESH

Flash floods are among the most devastating natural hazards affecting Bangladesh, particularly in coastal districts like Feni where unique hydro-meteorological, geographical, and socio-economic factors converge [38]. Unlike riverine or monsoon floods, flash floods are characterized by their sudden onset, high velocity, and short duration, often giving communities little to no time to prepare or respond [36]. The coastal region of Bangladesh is highly susceptible to flash floods due to its low elevation, flat terrain, intense rainfall, and proximity to upstream catchments in neighbouring India. In recent years, the frequency and intensity of flash floods have increased, fuelled by extreme weather events and changing land use patterns, including urban expansion and deforestation [30]. Feni district, located in the southeastern coastal belt of Bangladesh, lies at the intersection of these environmental and anthropogenic stressors. It has experienced recurrent flash flood events that have disrupted livelihoods, damaged infrastructure, and exposed weaknesses in disaster preparedness and governance [31].

2.4 CONCEPTUAL FRAMEWORK OF THE STUDY

This study's conceptual framework is based on the understanding that the complex interaction of exposure, susceptibility, and resilience across various dimensions (social, economic, physical, and environmental), what makes people

vulnerable to flash floods rather than just being physically exposed to a hazard [31]. The UNESCO-IHE vulnerability model, which views vulnerability as a function of both biophysical risk and socioeconomic capacity to endure and recover from unfavourable occurrences, is the framework used in this study [37]. This framework defines exposure as the existence of people, property, and systems in flood-prone areas; susceptibility as the likelihood that damage will be done to those exposed elements; and resilience as the ability to deal with, react to, and recover from the effects of flooding.

The framework conceptualizes flash flood vulnerability through the aggregation and spatial analysis of relevant indicators within each dimension. These indicators are spatially represented and normalized to create vulnerability indices for each dimension. This allows for the identification of vulnerability hotspots and the investigation of underlying drivers, which are further explored through primary data collection using semi-structured surveys and questionnaires. By grounding the research in this framework, the study purposes to provide a robust and holistic assessment that not only maps vulnerability but also explains why and how it varies across space and among communities.

2.5 DIMENSIONS OF VULNERABILITY

This study looks at four interrelated dimensions of flash flood vulnerability: social, physical, economic, and environmental. Every dimension reflects a crucial element of the community's vulnerability to flood threats, as well as its innate vulnerabilities and response and recovery capabilities [39]. A multi-scale knowledge of how many factors interact to determine vulnerability in the Feni region is made possible by the quantification of these dimensions using geospatial data.

The social vulnerability dimension captures the human and societal characteristics that influence susceptibility to harm [35]. In this study, exposure is represented by the density of population and the proportion of vulnerable age

groups. Susceptibility is gauged through indicators such as literacy rate, which reflects awareness and adaptive capacity, as well as the distance from healthcare facilities and the poverty rate, which both impact the ability to seek timely aid and maintain well-being during floods [40]. Resilience within this dimension is measured by the distance from the nearest flood shelter, a critical factor in determining the speed and safety of evacuation. In addition to spatial analysis, driver assessment reveals institutional challenges, such as corruption, bribery, inadequate healthcare, and weak community networks which further amplify social vulnerability, highlighting the role of governance and social cohesion in disaster response and recovery [28].

The physical vulnerability dimension involves the natural and built environment factors that influence how floodwaters affect the landscape and human settlements [41]. Exposure in this dimension includes slope, elevation, land use and land cover (LULC), drainage density, geology, and soil type, all of which determine how water accumulates and flows during flood events [33], [41], [42]. Areas with low elevation and poor drainage systems are more likely to experience prolonged inundation. Susceptibility is informed by the extent of past flood events, which offers insight into recurring risks and poorly protected zones. Resilience is represented by access to roads, which facilitates evacuation, the delivery of aid, and post-disaster recovery. From a community perspective, key drivers of physical vulnerability include poor infrastructure, insecure housing, limited mobility for the elderly and disabled, and critical shortages in water and food supply during floods, as reflected in the questionnaire responses.

The economic vulnerability factor focuses on the aspects of livelihood and finances that influence a community's capacity to endure and bounce back from the effects of flooding [43]. The level of urbanization and closeness to rivers, where livelihoods and financial resources are frequently concentrated in high-risk areas, determine exposure. Among those at risk are unemployment rates,

which restrict household income and weaken coping mechanisms. The recovery time from previous flood disasters is used to measure resilience in this dimension, serving as a stand-in for the capacity to resume regular economic activity. Other drivers are identified by primary data from the questionnaire, including lack of financial support programs, lack of inexpensive insurance, and exclusion from microcredit. These circumstances prolong cycles of vulnerability and poverty by preventing many households from making investments in safeguards or absorbing financial shocks.

The environmental vulnerability dimension focuses on ecological and climatic factors that affect exposure and recovery. Rainfall intensity is used as the main exposure variable, as heavy, concentrated rainfall is the primary trigger of flash floods in Feni. Susceptibility is represented by urban growth, measured through a built settlement growth index that captures the transformation of natural land into impermeable surfaces. Resilience is again assessed through recovery time, indicating how quickly the environment and local systems can rebound. Perceived environmental drivers like deforestation, wetland loss, and insufficient early warning systems are highlighted in questionnaire responses. The ability of the environment to absorb floodwaters and safeguard human settlements is diminished by regular erosion, pollution, and deterioration of natural buffers, as reported by communities located in low-lying floodplains [44], [45].

Together, these four dimensions and their associated variables offer a comprehensive lens to understand the spatial and systemic patterns of flash flood vulnerability in Feni district. By integrating both quantitative indicators and qualitative drivers, the study is equipped to generate evidence-based recommendations aimed at reducing risk and enhancing long-term resilience in vulnerable coastal communities.

2.6 DRIVERS OF FLASH FLOOD VULNERABILITY

Flash flood vulnerability in coastal regions like the Feni district is deeply intertwined with economic instability. One of the primary economic drivers of vulnerability is the widespread lack of employment opportunities, which weakens community resilience by limiting people's financial capacity to prepare for or recover from disasters. Wage theft and the absence of social safety net services, such as unemployment benefits or emergency aid, further exacerbate this fragility [46]. Many households in Feni also face exclusion from microcredit schemes and lack access to affordable insurance products, making it difficult to bounce back economically after flood events. Additionally, the high cost of preventive measures, such as elevating homes or purchasing water-resistant materials, is often unaffordable for low-income families. Without adequate savings or reliable government assistance programs, repeated flood exposure results in compounding financial losses, pushing vulnerable populations deeper into poverty and economic precarity [46].

Another important factor affecting the community's capacity to handle flash floods is social vulnerability. Many residents are left without the assistance they need during calamities as a result of delays or misallocations in flood relief and aid distribution caused by corruption and bribery in local authorities. Patronage arrangements can undermine equity in disaster response by favouring some groups over others. A major obstacle to preserving public health during and after flood occurrences is inadequate access to healthcare, both financially and geographically. These situations are made worse by inadequate sanitary infrastructure, particularly in congested or low-lying locations. Furthermore, a lack of community networks and poor social cohesion restrict collective action in the face of disasters, and language and cultural obstacles may prevent some groups from accessing critical flood preparedness information [47].

Another important factor contributing to vulnerability to flash flooding is exposure to natural hazards and environmental deterioration. Since many of Feni's settlements are situated in low-lying areas or active floodplains, they are naturally more vulnerable to unexpected flooding. Mismanagement of the environment, such as pollution and deforestation, can decrease the land's natural ability to absorb water, increasing surface runoff during periods of intense precipitation. The degradation of protective ecosystems like wetlands further diminishes natural flood defences [48]. Additionally, the absence or inefficiency of early warning systems hampers timely evacuations and preparedness, leaving people exposed during critical periods.

Lastly, vulnerability to flash floods is greatly increased by physical constraints. The ongoing fear of eviction for many households in flood-prone parts of Feni threatens long-term housing stability and makes it challenging for families to make investments in long-term flood-resilient buildings. Water scarcity and contamination during floods become major problems that impact daily living, health, and cleanliness. Particularly in isolated or rural locations, inadequate transportation infrastructure and damaged roads make evacuation difficult and cause delays for emergency services [49]. Communication and access to essential services are further disrupted by inadequate or unstable electrical networks. Additionally, dwellings are more vulnerable to water damage when they have weak construction and poor building quality. Residents who are elderly or disabled face additional difficulties because shelters and evacuation routes are inaccessible. These issues are made worse by insecure land tenure and the disruption of regional food supply chains during floods, which emphasizes the urgent need for resilient, inclusive physical development as well as investment in vital infrastructural systems [27], [29], [43].

2.7 POLICY FRAMEWORK AND RESILIENCE

To manage the growing dangers of floods, especially in light of climate change and expanding urbanization, Bangladesh has created a number of strategic national and regional policy tools. The National Water Management Plan (2001) and the National Water Policy (1999) place a strong emphasis on floodplain zoning, sustainable water resource management, and enhanced collaboration amongst water management bodies. In addition to encouraging community-based risk reduction and incorporating disaster risk management into national development planning, the National Disaster Management Policy (NDMP) offers a thorough framework for disaster preparedness, response, and recovery [50], [51], [52], [53].

The Disaster Management Act (2012) and the Standing Orders on Disaster (2019) provide early warning, evacuation, and relief protocols as well as institutional roles and duties for flood risk management [50], [54]. In order to safeguard the deltaic areas, including Feni, the Bangladesh Delta Plan 2100 (BDP 2100) integrates sustainable development, climate resilience, and water resource management from a long-term viewpoint [55]. Given Bangladesh and India's similar upstream-downstream flood dynamics, the SAARC Framework for Action (SFA) promotes transboundary collaboration in disaster risk reduction and climate adaptation at the regional level [56].

Resilience has become a key idea in this policy environment, moving the emphasis from reactive disaster response to proactive risk reduction and adaptive capacity creation. The ability to foresee, absorb, and adjust to flood hazards is another aspect of resilience, in addition to the ability to recover from a disaster. Thus, mobilizing resources, coordinating institutions, and matching policies to local requirements are all necessary for effective flood risk management. But there are still gaps between the creation and application of policies, especially at the municipal level. Because top-down approaches

frequently overlook local knowledge, social dynamics, and regional variations in risk exposure, this divergence might prolong vulnerabilities at the community level [57]. To improve local flood resilience, it is imperative to evaluate the operationalization and applicability of these policies require modification as well as institutional strengths.

2.8 ANALYTICAL FRAMEWORK OF THE STUDY

This study's analytical framework integrates field data and quantitative geospatial research to operationalize the theoretical components of vulnerability. Under the broad categories of social, economic, environmental, and physical vulnerability, the study starts with the identification and standardization of pertinent indicators. Pre-processed geospatial data, such as satellite imagery, DEM, LULC, population density, and hydrological datasets, are transformed into raster layers of 30 by 30 meters. Principal Component Analysis (PCA) is used to normalize and weight these layers in order to create composite indices for every vulnerability dimension. A thorough geographical vulnerability map for the Feni district is then produced by superimposing these indicators, highlighting regions with differing levels of vulnerability.

Primary data is gathered via structured questionnaires to supplement the geospatial analysis. The questionnaire uses Likert-scale responses to measure community perceptions and lived experiences. It is developed around the main determinants of vulnerability, including socioeconomic stresses, environmental conditions, infrastructure access, and governance quality. This mixed-methods approach reveals the underlying socio-political and economic drivers that influence flood risk in addition to validating the spatial patterns found using geographic information systems.

Due to the multifaceted and intricate nature of flood risk, a mixed-methods design is necessary. Although geospatial analysis offers useful spatial insights into susceptibility, exposure, and resilience, it frequently overlooks the subtle,

context-specific factors that influence vulnerability patterns on the ground. By combining these techniques, the study guarantees a more comprehensive comprehension of vulnerability, allowing for more focused and useful suggestions for lowering the vulnerability of flooding in the Feni district.

2.9 SUMMARY

This chapter discusses the study's approach to assessing flash flood vulnerability in Feni district, Bangladesh. It explores flash floods sudden onset, ecological triggers, and socio-economic consequences. The vulnerability is defined as exposure, susceptibility, and resilience across four dimensions: social, economic, environmental, and physical. Key drivers of vulnerability include socioeconomic inequality, inadequate infrastructure, environmental degradation, and governance failures. The chapter also reviews national and regional policy instruments and their potential to enhance or hinder local resilience. The analytical framework, grounded in a mixed-methods design, illustrates how spatial analysis and community perspectives are combined to generate a comprehensive vulnerability assessment.

Chapter 3: STUDY AREA PROFILE

This chapter outlines the research design and technique used in the study. It describes how the data was gathered, examined, and evaluated in order to respond to the research questions and accomplish the objectives previously mentioned in the document. The chapter begins with a description of the study area, details on the overall research strategy, and an explanation of the rationale for the research strategy selection. An explanation of the methods utilized for data collection, sampling, and analysis comes next.

3.1 STUDY AREA PROFILE

3.1.1 General Description

The administrative division of Chattogram includes the Feni District, which is situated in the southeast coastal region of Bangladesh (Figure 3.1). With a total area of roughly 928.34 square kilometers, it is among the smaller districts in the area [27]. Its topography consists of floodplains, low-lying areas, and a few elevated regions, making it highly exposed to flooding. The Feni, Muhuri, rivers, along with intense monsoon rainfall (averaging 2500–3000 mm annually), exacerbate flood risks [27], [58].

3.1.2 Climatology

The climate of Feni District is tropical, with heavy monsoon rains received from June to September. The average annual rainfall is about 2900 mm, out of which the monsoon contributes more than 80%. The warm and humid climate prevailing in the district contributes to flash floods [58].

3.1.3 Physical Features

The drainage system in the area is low-performing and often fails to cope with the enormous amounts of water, creating prolonged periods of static water and common flooding phases [59]. The flat nature of the land, the seasonal rains,

and the closeness to big rivers make this district vulnerable to both seasonal flood occurrences and flash floods due to heavy rains or the release of water from other surrounding locations [60].

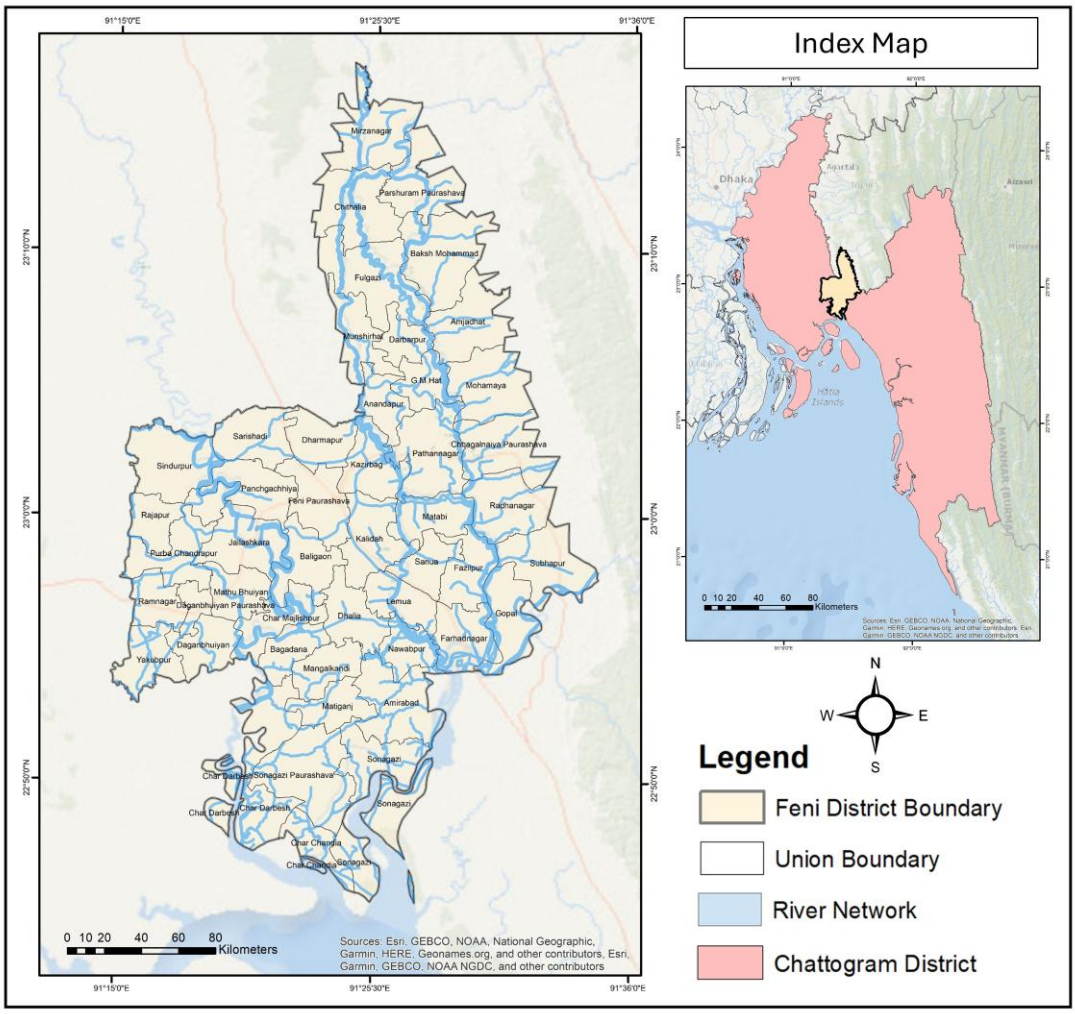


Figure 3.1 Geographical Location and Extent of the Study Area.

3.1.4 Previous Flood Events

Feni District has had a long history of flood events due to its geographical location in the flood hazard area of Bangladesh. It is often hit by seasonal flooding during the monsoon, along with flash flooding due to extreme weather events and releases from upstream in India [61]. Historically, considerable floods occurred in this area in 1998, 2004, 2010, and 2017 [58]. All these incidents brought huge losses to property, infrastructure and agriculture, and displaced a large number of people [59]. In August 2024, the area faced a severe flash flood, and its

magnitude brought forth the necessity of carrying out a thorough flood vulnerability assessment of the district [61]. The flood situation submerged several upazilas and people were cut off from communication, power and other basic amenities for weeks [62]. More than 137,500 people were rendered homeless but remained within waterlogged conditions, and 78 emergency shelters were opened to provide housing for over 40,000 displaced people [62], [63], [64].

3.1.5 Justification of Selection

Feni District was selected for this study because of its historical susceptibility to floods, which is influenced by socioeconomic and topographical variables [64]. The district's strategic placement inside an active flood danger zone makes it one of Bangladesh's most flood-prone areas. Apart from its historical susceptibility, Feni District is a crucial case study for assessing flood risk reduction tactics in an environment where increasing urbanization and climate change are making disaster management more difficult [63]. The area is well suited to evaluating the interaction between environmental dangers and human systems due to its varied socioeconomic structure and changing land-use patterns [65]. This in-depth knowledge is crucial for creating focused adaptation and resilience-building strategies that may be successfully incorporated into practice and policy, not just in Bangladesh but also in other internationally vulnerable regions.

Moreover, the 2024 flash flood event, which severely affected Feni and displaced hundreds of thousands of people, highlights the urgency of conducting vulnerability assessments in this district. The disproportionate impacts across its six upazilas also make Feni an ideal site to explore spatial variability in vulnerability and the underlying drivers that exacerbate flood risks [61].. Its mix of rural and urban settlements, coupled with the presence of key infrastructure and agricultural dependency, provides a comprehensive setting to examine multidimensional vulnerabilities.

Chapter 4: METHODOLOGY

This chapter outlines the research design and technique used in the study. It describes how the data was gathered, examined, and evaluated in order to respond to the research questions and accomplish the objectives previously mentioned in the document. The chapter begins with a description of the study area, details on the overall research strategy, and an explanation of the rationale for the research strategy selection. An explanation of the methods utilized for data collection, sampling, and analysis comes next.

4.1 SELECTION OF VARIABLES

In this study, a comprehensive set of indicators (exposure, susceptibility, resilience) was used to assess flood vulnerability across four key dimensions [37]. To assess these indicators, several variables have been selected based on a mixed deductive–inductive approach (Table 4.1). The geospatial input datasets originated from multiple sources, with varying native spatial resolutions. Population density, vulnerable age groups, poverty, and urban growth layers were obtained from WorldPop at a native resolution of 100 m (Table 4.1). The education and healthcare facility data were collected as building-level and point vector datasets, respectively, from HDX. Shelter locations were acquired from GeoDASH as vector points (Table 4.1). Terrain-related layers, including slope, elevation, and drainage density, were derived from the SRTM DEM at 30-m resolution. Land use/land cover (LULC) and urbanized area layers were sourced from the Esri Global LULC dataset at 10 m. Geology and soil type layers were polygonal datasets obtained from USGS and FAO, with resolutions of 1 km. The previous flood extent and recovery time layers were generated from Sentinel-1 SAR data at 10-m resolution (Table 4.1). Road and river networks were retrieved as vector line data from OpenStreetMap (OSM) and LGED, respectively. Rainfall data were obtained from NASA POWER, originally gridded at 0.5° resolution

(~50 km). Finally, unemployment data were obtained from the UNISDR GAR database at 1 km resolution (Table 4.1). For integrated geospatial analysis, these disparate datasets were then harmonized to a consistent spatial resolution of 30 m.

Table 4.1. Description of various variables related to different vulnerability indicators.

Variables	Format	Description	Source
Population Density	Gridded data	People number in each grid cell.	WorldPop "https://dataforgood.facebook.com/dfg/tools/high-resolution-population-density-maps (accessed on 24-01-25)"
Vulnerable age group	Gridded data	The number of vulnerable individuals in each grid cell (male or female, aged <15 or >65).	Age and sex structure Index data from WorldPop "https://hub.worldpop.org/project/categories?id=8 (accessed on 24-1-25)"
Education	Gridded data	Number of educational establishments in each grid cell.	Humanitarian Data Exchange "https://data.humdata.org/ (accessed on 24-1-25)"
Healthcare facility	Map (geographical location)	The Euclidean distance between the current healthcare facilities.	
Poverty	Gridded data	Value of the wealth index for each grid cell.	Wealth Index data "https://hub.worldpop.org/geodata/summary?id=1274 (accessed on 24-1-25)"
Shelter	Map (geographical location)	Euclidean distance to the shelters that are in place.	GeoDASH "http://data.gov.bd/dataset/geodash/resource/808b3ae3-d1f5-4f1e-ae3c-3a360400a9e3 (accessed on 24-01-25)"
Slope	Gridded data	Computed with the DEM.	Estimated from DEM

Elevation	Gridded data	A spatially resolved digital elevation model (DEM) at 30 m.	
Land use/land cover	Gridded data	Whether a land cover type is a built-up area or not is indicated by each grid cell.	Esri Global Land Cover Map "https://livingatlas.arcgis.com/landcover/ (accessed on 24-01-25)"
Drainage density	Gridded data	Calculated with the DEM.	Estimated from DEM
Geology	Map of polygon feature	A number of geologic maps were taken in support of the 2000 World Petroleum Assessment (DDS60), providing almost worldwide coverage of coarse resolution surface geology.	"https://www.usgs.gov/centers/central-energy-resources-science-center/science/world-geologic-maps (accessed on 24-01-25)"
Soil types	Gridded data	FAO soil maps and databases refer to data and maps compiled using field surveys backed up by remote sensing.	Food and Agriculture Organization (FAO) "https://data.apps.fao.org/map/catalog/srv/eng/catalog.search#/home (accessed on 24-01-25)"
Previous Flood Extent	Gridded data	Coverage of flood in 2024 flood event	Estimated from Sentinel 1 Image Processing in GE
Access to Roads	Gridded data	Euclidean distance to the current roadway system.	Derived from OpenStreetMap "https://www.openstreetmap.org/#map=7/23.721/90.351 (accessed on 24-01-25)"
Rainfall Intensity	Gridded data	Daily precipitation data from 2017 to 2024.	Precipitation Data "https://power.larc.nasa.gov/ (accessed on 24-01-25)"
Urban growth	Gridded data	Annually modelling built-settlements between remotely-sensed observations using relative changes in subnational populations and lights at night	WorldPop Urban change "https://hub.worldpop.org/project/categories?id=7(accessed on 24-01-25)"
Recovery time to floods	Gridded data	Recovery from flood event occured in 2024	Estimated from Sentinel 1 Image Processing in GE
Urbanized Area	Gridded data	Each grid cell indicates whether the land cover	Esri Global Land Cover Map "https://livingatlas.arcgis.com/L

		type is a built-up area or not.	andcover/(accessed on 24-01-25)"
Contact with River	Gridded data	Euclidean distance from the rivers	Estimated from LGED river shapefile
Unemployment	Gridded data	Density estimation of unemployed population	Global Assessment Report (GAR) on disaster risk reduction 2015 dataset by UNISDR "http://surl.li/fjcril (accessed on 24-01-25)"

4.1.1 Variables for Social Vulnerability

Social vulnerability is assessed through several important indicators. For assessing exposure, variable population density (Figure 4.1a), is crucial, as areas with higher population densities are likely to experience greater disruption during flood events [45]. Another social exposure variable is vulnerable age group (people younger than 15 or older than 65 years). Figure 4.1b is used to capture the number of individuals within these vulnerable age groups, which is significant since they are more susceptible to the adverse effects of floods [30]. Flood shelters were used as a measure of resilience, with data showing the number and location of shelters in each region, impacting the population's ability to seek immediate relief (Figure 4.1c) [32].

In assessing susceptibility, literacy rate (Figure 4.1d) is another key factor, and measures the availability of educational institutions, which is important for disaster preparedness and response capabilities [32]. In addition, proximity to healthcare facilities (Figure 4.1e) is considered a social susceptibility indicator, as access to healthcare can reduce casualties during floods.

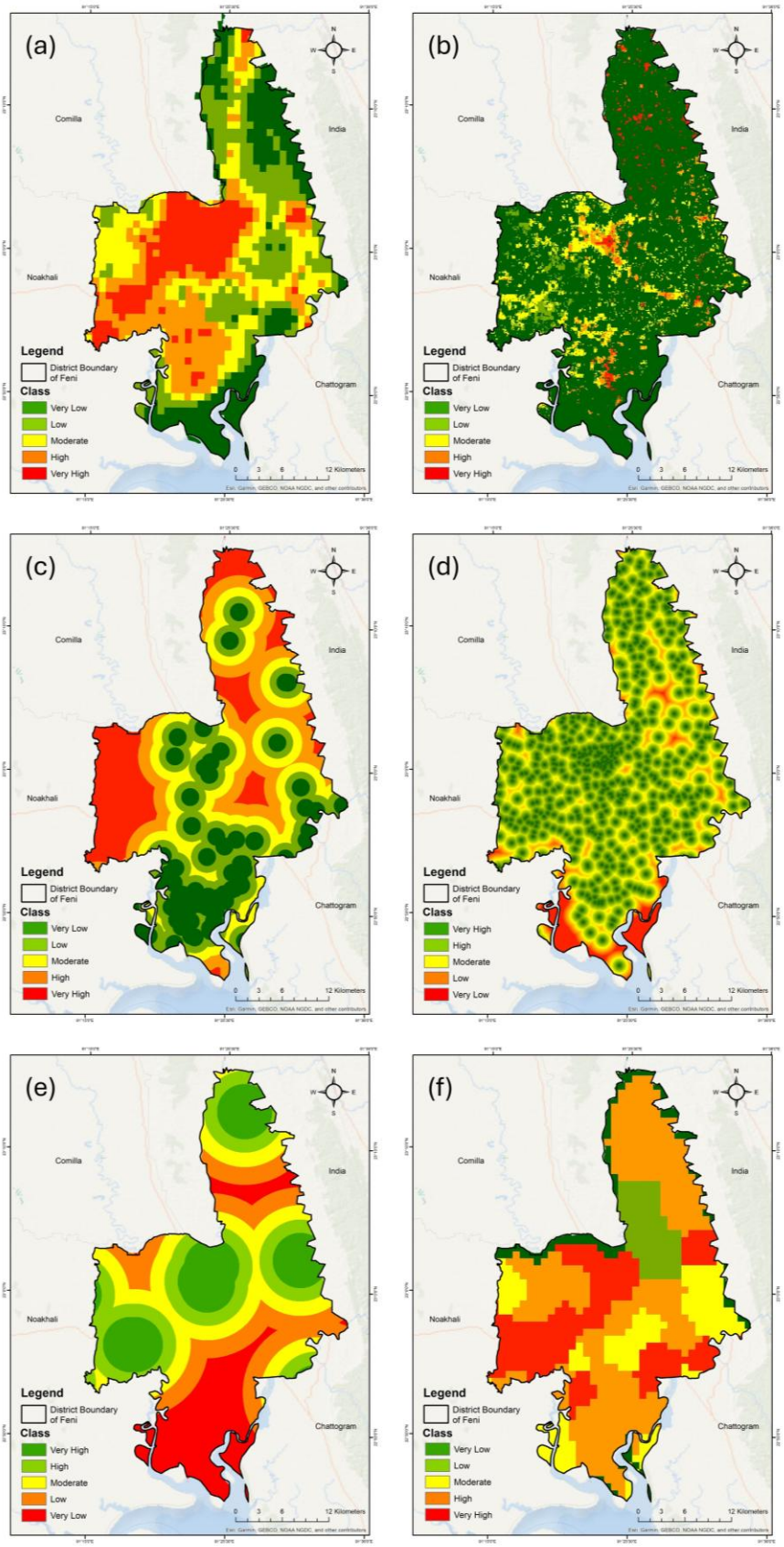


Figure 4.1. Variables under exposure: (a) Density of population; (b) Density of vulnerable age group; Resilience: (c) Distance from shelter; Susceptibility: (d) Literacy rate; (e) Distance from healthcare facilities; (f) Rate of poverty.

This indicator measures the distance to the nearest health facilities [43]. Finally, poverty rate (Figure 4.1f) is used to measure the rate of poverty, which impacts the population's ability to recover [45].

4.1.2 Variables for Physical Vulnerability

In this study, the assessment of physical vulnerability to flash floods was based on a comprehensive collection of datasets (Table 4.1). To assess exposure, as depicted in Figure 4.2a,b, slope and elevation data were utilized to analyze the topographical features that influence runoff patterns and flood propagation [66]. Steeper slopes typically increase the velocity and volume of surface runoff, thereby heightening the potential for rapid flood onset and greater impact [39].

Figure 4.2c presents land use data, which provides insights into how different land cover types affect flood dynamics and vulnerability levels [67]. Understanding the distribution and characteristics of land use is fundamental in determining how various surfaces interact with floodwaters, either mitigating or exacerbating flood risks [66]. Figure 4.2d illustrates drainage density, a measure of the river and stream networks that direct floodwaters through the landscape [68]. In Figure 4.2e,f, soil type and geology further contribute to physical vulnerability, as certain soil types and geological conditions absorb water differently, impacting flood risks [58]. Historical flood extents (Figure 4.2g) are also factored in to determine areas previously affected by floods and to assess susceptibility, providing context for chronic vulnerability [69].

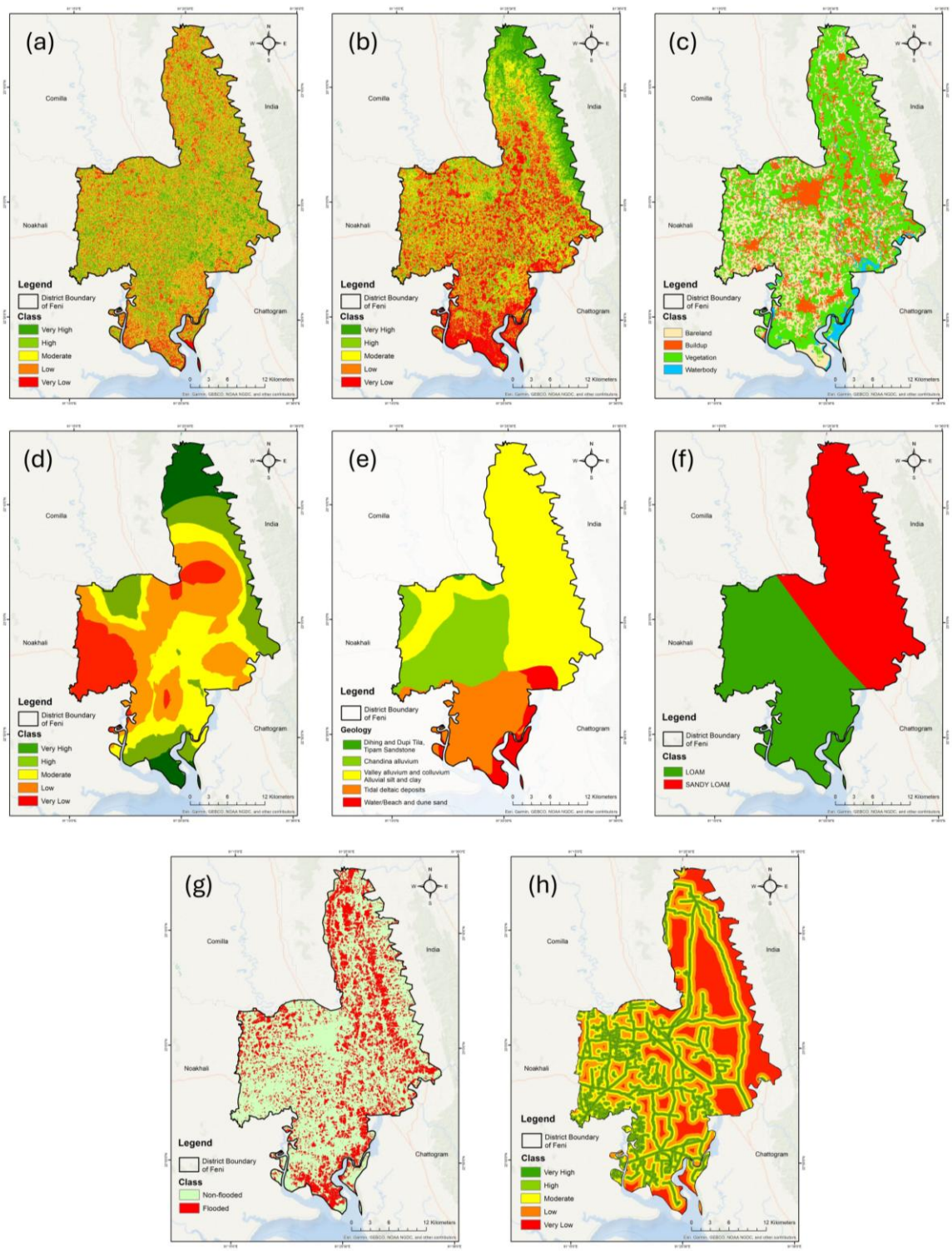


Figure 4.2. Variables under exposure: (a) Slope; (b) Elevation; (c) LULC; (d) Drainage density; (e) Geology; (f) Soil type; Susceptibility: (g) Previous flood extent; Resilience: (h) Access to road.

Finally, to assess resilience, Figure 4.2h focuses on access to roads, which is critical for emergency response and evacuation during flash flood events. Efficient road networks facilitate timely assistance and reduce the risk of prolonged exposure to flood hazards [31].

4.1.3 Variables for Economic Vulnerability

Economic vulnerability focuses on the relationship between financial stability and flood impacts (Table 4.1) [33]. To assess exposure, the percentage of urbanized areas (Figure 4.3a) is a critical variable, as urban regions often experience more severe flooding due to impervious surfaces that prevent water absorption [70].

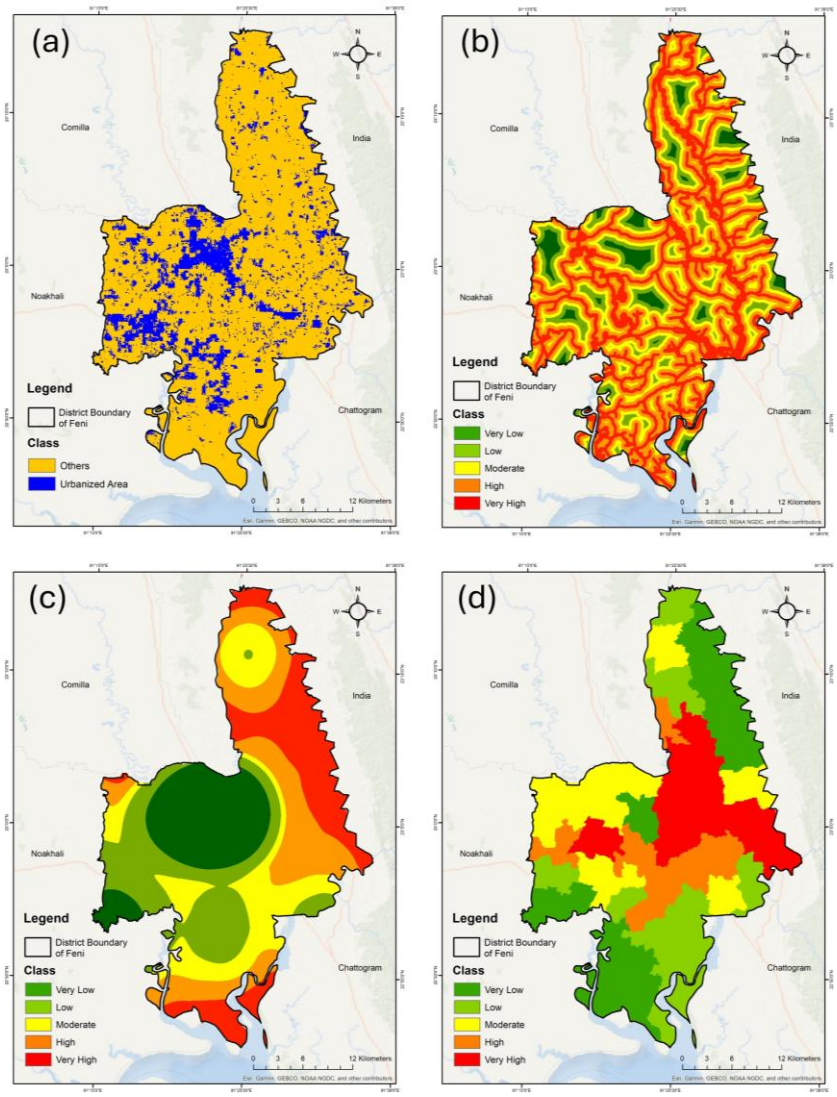


Figure 4.3. Variables under exposure: (a) Urbanized area; (b) Contact with river; Susceptibility: (c) Unemployment; Resilience: (d) Recovery time to flood.

In addition, proximity to rivers increases flood risks (Figure 4.3b), with this indicator measuring how much of the population lives near major rivers [58]. High unemployment rates are considered an economic susceptibility factor (Figure 4.3c), as communities with high unemployment typically have fewer resources to recover from flood events [43]. Recovery time to floods, based on past experience, is also used as an indicator of resilience in the economic dimension (Figure 4.3d) [58]. This factor measures how quickly communities have historically recovered from flood-related economic damage, providing insight into their ability to withstand future events [68].

4.1.4 Variables for Environmental Vulnerability

Environmental vulnerability is analyzed using several key variables (Table 4.1). For assessing exposure, rainfall intensity, calculated from a 60-year average, (Figure 4.4a) measures the exposure of different regions to extreme rainfall events. Areas with higher average rainfall intensities are more prone to flash floods [66].

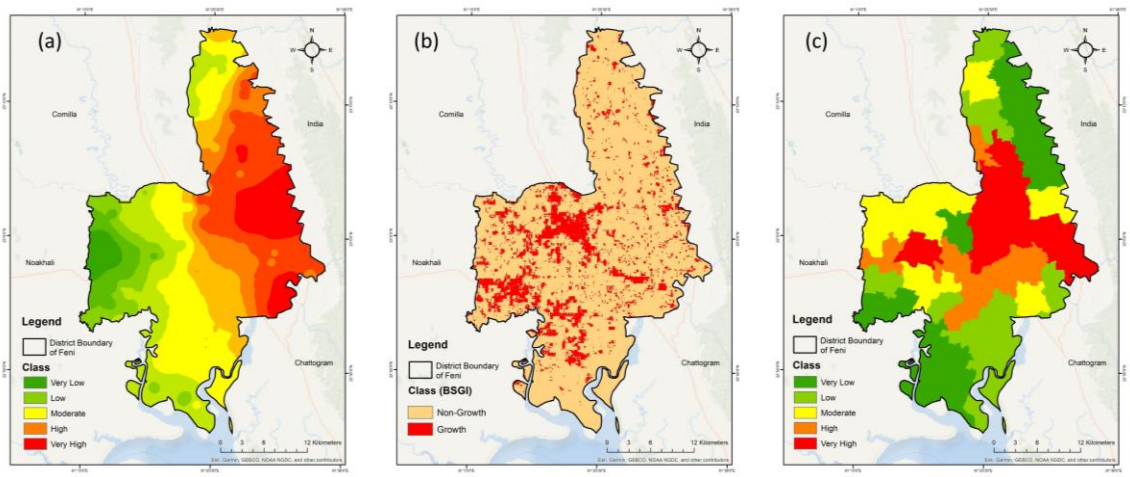


Figure 4.4. Variables under exposure: (a) Rainfall intensity; Susceptibility: (b) Urban Growth (Build Settlement Growth Index); Resilience: (c) Recovery time after flood.

Urban growth (Figure 4.4b) is considered a susceptibility factor in assessing environmental vulnerability, as rapidly growing urban areas tend to have more

impervious surfaces and insufficient drainage systems, exacerbating flood risks [71]. Lastly, environmental resilience is measured by the recovery time from previous flood events (Figure 4.4c), assessing how quickly regions recover after floods (Figure 4.4) [72].

Each of these variables under three different indicators plays a critical role in building a comprehensive understanding of flash flood vulnerability in Feni District [68]. By integrating these diverse datasets and analysing them through a geospatial approach, the study provides a nuanced perspective on the multifaceted nature of flood vulnerability in the region.

4.2 DATA PRE-PROCESSING

Prior to vulnerability assessment, a systematic data pre-processing approach was used to guarantee the consistency, and scientific rigor of the geospatial analysis. This was performed on all spatial data layers to get a uniform spatial resolution of 30 m, in order to ensure analytical consistency across datasets from diverse sources and different spatial formats. The decision to adopt this resolution was primarily guided by the native resolution of the SRTM DEM, which served as the foundational dataset for several derived layers, such as elevation, slope and drainage density. Additionally, a 30-m grid provides an optimal balance between spatial detail and computational efficiency, especially for district-scale flood vulnerability assessments [73], while also being compatible with medium-resolution remote sensing products and widely used in similar geospatial studies in Bangladesh [74].

Following this, all datasets were projected to a common coordinate reference system (WGS 84) to ensure geospatial interoperability and eliminate spatial misalignments during overlay and raster calculations. For datasets provided in vector formats (e.g., education facilities, health centres, shelters, road and river networks, geology polygons), vector-to-raster conversion was executed using the spatial analysis tool in ArcGIS. Point features were rasterized based on

Euclidean distance from each feature's centroid, while polygon features, such as geology, were converted using the majority rule within each raster cell. Line features, such as roads and rivers, were converted to distance raster that calculates the shortest path from each grid cell to the nearest feature. Once all data layers were in raster format, they were resampled to the target resolution using an interpolation technique. Specifically, continuous variables (e.g., rainfall, elevation, poverty index) were resampled using bilinear interpolation, preserving smooth gradients, while categorical or discrete datasets (e.g., LULC, soil type, geology) were resampled using nearest neighbour interpolation to maintain class integrity. All rasterized layers were then normalized to a uniform scale to facilitate multi-criteria evaluation. Subsequently, these processed layers were classified into five vulnerability categories using natural breaks (Jenks) classification to prepare the base maps of individual variables (Figures 4.3–4.4), which were then used to compute final vulnerability layers.

4.3 NORMALIZATION OF DATA

Normalization in this study is used in making the diversified spatial data comparable and effective to analyze. It brings all variables down to a common scale, which is critical for weight generation in order to study the variables in similar units [75]. In this study, min–max normalization was applied, turning raw data values to a common scale between 0 (indicating the lowest susceptibility) and 1 (indicating the highest vulnerability). This is also useful for comparing maps using a quartile classification process [76]. The min–max normalization for each indicator has been carried out using Equation (4.1):

$$y_{ij} = (x_{max} - x_{min})/(x_{ij} - x_{min}) \quad (4.1)$$

where y_{ij} is the normalized value of the j-th indicator for the i-th spatial unit, x_{min} and x_{max} are the indicator's minimum and maximum values, respectively, and x_{ij} is the indicator's original value.

Another important fact that had to be considered when applying normalization was the direction of the relationship between the indicator and vulnerability. For all those variables where, higher values showed a greater relationship with vulnerability, such as population density or unemployment, the normalization process has been applied directly.

However, for those indicators where higher values meant lower vulnerability or greater resilience, such as access to roads or flood shelters, the normalization formula has been reversed. In this way, in all instances, a high normalized value represented higher vulnerability.

These normalized data were then prepared for PCA, which generated weights for each variable. Normalization not only provided a fair comparison between these diverse data types but also set the bedrock on which these variables can be accurately integrated into the overall geospatial model of vulnerability.

4.4 WEIGHT GENERATION

Weighting of the various variables corresponding to each indicator of the dimensions of vulnerability is necessary to integrate the variables, in order to assess the actual flood vulnerability condition across Feni District (Figure 4.5). Generation of weights for such variables was performed using PCA, which reduces the complexity of multi-dimensional data into lower dimensions, while retaining most critical features of the original data [35]. This approach will allow meaningful components to be extracted from the data, whereby the absolute importance for each variable will be derived [77].

The PCA considers the maximum variance, which allows grading of the priorities of regions in terms of the most important factors, without subjective weighting [78]. This is a data-driven approach and highly accurate in the sense that it is free from the frequent dependency of other MCDM techniques, such as AHP, TOPSIS, and SAW, on subjective weight assignment for the criteria [35]. While AHP is useful in decomposing complex decisions, it may be biased and requires too much time when used on large datasets [77]. Similarly, though useful in ranking alternatives, TOPSIS and SAW require assignments of weight and are not as effective with related variables when compared to PCA. The greatest advantage of PCA is the fact that it handles very large datasets consisting of several interrelated indicators to ensure that the selection of influential factors is not influenced by human bias [77]. This makes it a robust and logical choice for studying flood vulnerability, as it reduces complicated datasets to simpler forms and gives a more reliable and data-centric output when compared to other MCDM methods.

In order to confirm the dataset's fitness for PCA, the study performed two fundamental statistical tests: the Kaisa–Mayer–Olkin (KMO) test [44] and Bartlett's test of sphericity [79]. Statistical testing of data completeness and of the appropriateness of the variables for factor analysis are the purposes of these tests.

The KMO test was used to measure sampling adequacy, which checks the strength of the relationships among variables. The KMO value ranges between 0 and 1; the closer the value is to 1, the more proper the dataset is for PCA. The next test is Bartlett's, which reports on whether the correlation matrix was significantly different from an identity matrix, in which all variables would be uncorrelated. This test showed a significant *p*-value, $p < 0.05$, indicating that there is significant correlation among the variables, thus making them suitable for PCA [79]. After confirmation of adequacy via these tests, the

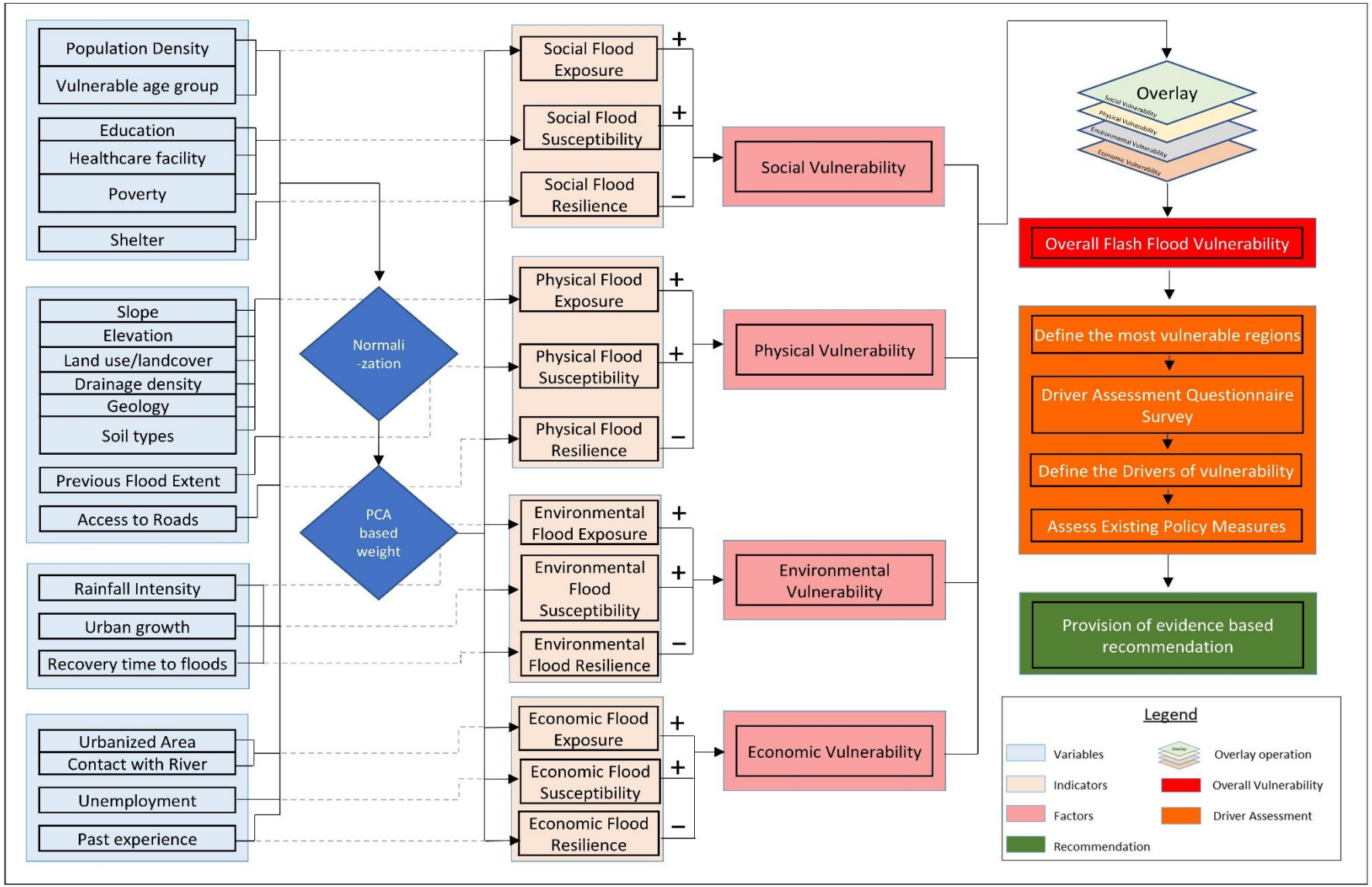


Figure 4.5. Methodological Workflow Diagram of the Research Process.

communalities were calculated. Communalities refer to the proportion of variance for each variable explained by the components extracted from PCA [80]. This was an important step to ascertain that each variable contributed meaningfully to the overall analysis, hence ensuring the reliability of the weights generated.

4.4.1 Principal Component Analysis (PCA)

The data gathered for different flood vulnerability factors were structured in a matrix form, where each observation is denoted by a row and each variable, pertaining to an indicator of vulnerability, is represented by a column. The first step in the analysis involved transforming each variable into a z-score for the variable using Equation (4.2) [81]. This standardization makes certain that no variable contributes less or more to the PCA:

$$Z_{ij} = \frac{X_{ij} - \mu_i}{\sigma_i} \tag{4.2}$$

Where Z_{ij} is denoted as the standardized value of the ith variable for the jth observation and X_{ij} is the actual value, μ_i being the mean and σ_i being the standard deviation of the ith variable, respectively.

After the normalization of data, the covariance matrix of the variables was calculated using (Equation (4.3)). This shows the variance between the flood vulnerability indicators, bringing out how most vary together [79]:

$$C = \frac{1}{n-1}\sum_{j=1}^{n}(X_j - \underline{X})(X_j - \underline{X})^T \tag{4.3}$$

where C represents the covariance matrix, X_j denotes the standardized values for the j-th factor, and $\underline{X}$ refers to the average vector for all the factors.

The covariance matrix is used for further calculations of eigenvalues and eigenvectors using (Equation (4.4)). Therefore, to eliminate the principal components, it was necessary to perform eigenvalue decomposition on the covariance matrix [79]:

$$C_v = \lambda_v \tag{4.4}$$

where v is an eigenvector corresponding to a certain principal component, and λ is the corresponding eigenvalue.

In this way, the principal components directions are defined by the eigenvectors, while the variance proportion explained by each component is given by the eigenvalues. The first principal component explains the maximum level of variance in the dataset while the other components will explain progressively less variance [79]. Based on this, the loading for each variable for the principal components was obtained through the analysis of the eigenvectors (Equation (4.5)):

$$L_{ik} = v_{ik} \tag{4.5}$$

where L_{ik} is the loading of the i-th variable on the k-th principal component, and v_{ik} is the corresponding eigenvector element.

The loadings show the impact of each variable on each principal component in a comparative manner. To measure the contribution of individual variables to the principal components, the loadings were squared using Equation (4.6). This eliminates any values that are negative and offers a measure of the total contribution of each variable to the variance explained. The loadings squared for the variables were then aggregated over all principal components to obtain the overall contribution of each variable using Equation (4.7):

$$L_i^2 = (v_i)^2 \tag{4.6}$$

$$\text{Total squared loading } S_i = \sum_{k=1}^{p} {L_{ik}}^2 \tag{4.7}$$

Where p is the number of principal components that are kept according to their eigenvalues.

This sum depicts the average contribution of each variable in explaining the variation contained within the flood vulnerability. In order to provide weights for the indicators, the squared loadings were made relative by dividing each by the total sum of squared loadings for all variables using Equation (4.8) [78]:

$$W_i = \frac{Total\ squared\ loadings_i}{\sum_{i=1}^{n} Total\ squared\ loadings_i} \tag{4.8}$$

where W_i is the normalized weight for the i-th variable, and n is the total number of variables.

To ease comprehension, these weights were expressed as percentages. The obtained weights suggest how relevant each flooding vulnerability variable level assessment is [78]. These weights were subsequently employed to fuse the various factors into a single index and thus allowed for flood vulnerability assessment over the study area in a more complete manner.

4.5 FLOOD VULNERABILITY ASSESSMENT FRAMEWORK

In this study, flood vulnerability assessment was based on a systematic framework set up by Equation (4.9), issued by UNESCO-IHE [37]. This framework enables the various aspects of vulnerability to be addressed and helps to integrate different elements that contribute to and increase vulnerability to floods. The formula which assesses vulnerability in this study is expressed as follows:

$$\text{Vulnerability} = \text{Exposure} + \text{Susceptibility} - \text{Resilience} \quad (4.9)$$

In this study the components of the (equation 3.9), are referred as the indicators of vulnerability and the indicators have several variables in it. According to the generated weights of the PCA, the variables were integrated together to form the spatial layer of these indicators. Which is been done following the (equation 3.10).

$$\text{Indicator}_{(\text{Exposure, Susceptibility, Resilience})} = W_1 \times V_1 + W_2 \times V_2 + \ldots + W_n \times V_n \quad (4.10)$$

Where $W_{(1 \text{ to } n)}$ are the weights generated from PCA and the variables $V_{(1 \text{ to } n)}$ are the variables specified in Table 3.1.

The method offers a uniform framework for understanding flood vulnerability by integrating three major indicators. The meaning of exposure in this context is the degree to which a geographical area or a demographic group is exposed to the impacts of flood hazards [82]. The term susceptibility stands for their respective intrinsic attributes that predispose them to be negatively affected [67]. Resilience is the ability to withstand or recover from floods [83]. The formula makes it clear that exposure and susceptibility contribute to vulnerability, while

resilience acts to reduce it. In this way and using this formula to analyze the collected spatial data, the study succeeded in producing vulnerability maps that incorporate these components and show their relationship throughout the Feni District.

4.6 SAMPLING SITE SELECTION

The choice of sampling sites is an essential component in gaining an understanding of the flash flood susceptibility in the Feni district. This is because the selection of sampling sites has a direct impact on the reliability and representativeness of the findings of the study [84]. The dynamic character of flood occurrences and the spatial heterogeneity of these events prompted the adoption of a methodical approach (figure 4.6).

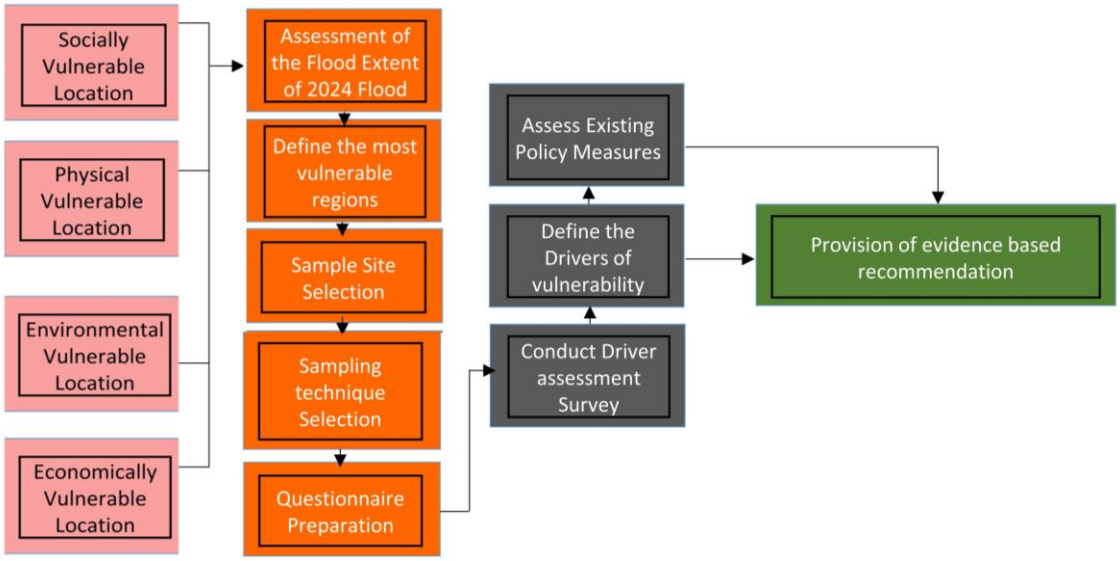


Figure 4.6 Workflow of driver assessment and recommendation generation

This was done to ensure that the selected sites properly represent the various dimensions of variables that contribute to vulnerability. The selection process integrated remote sensing techniques, population density data, and field observations to identify the most affected and at-vulnerable areas for survey implementation. Based on the output of first objective, the study delineated the flood vulnerable zone, covering an estimated area of 26,520 hectares, by using Sentinel-1 imagery.

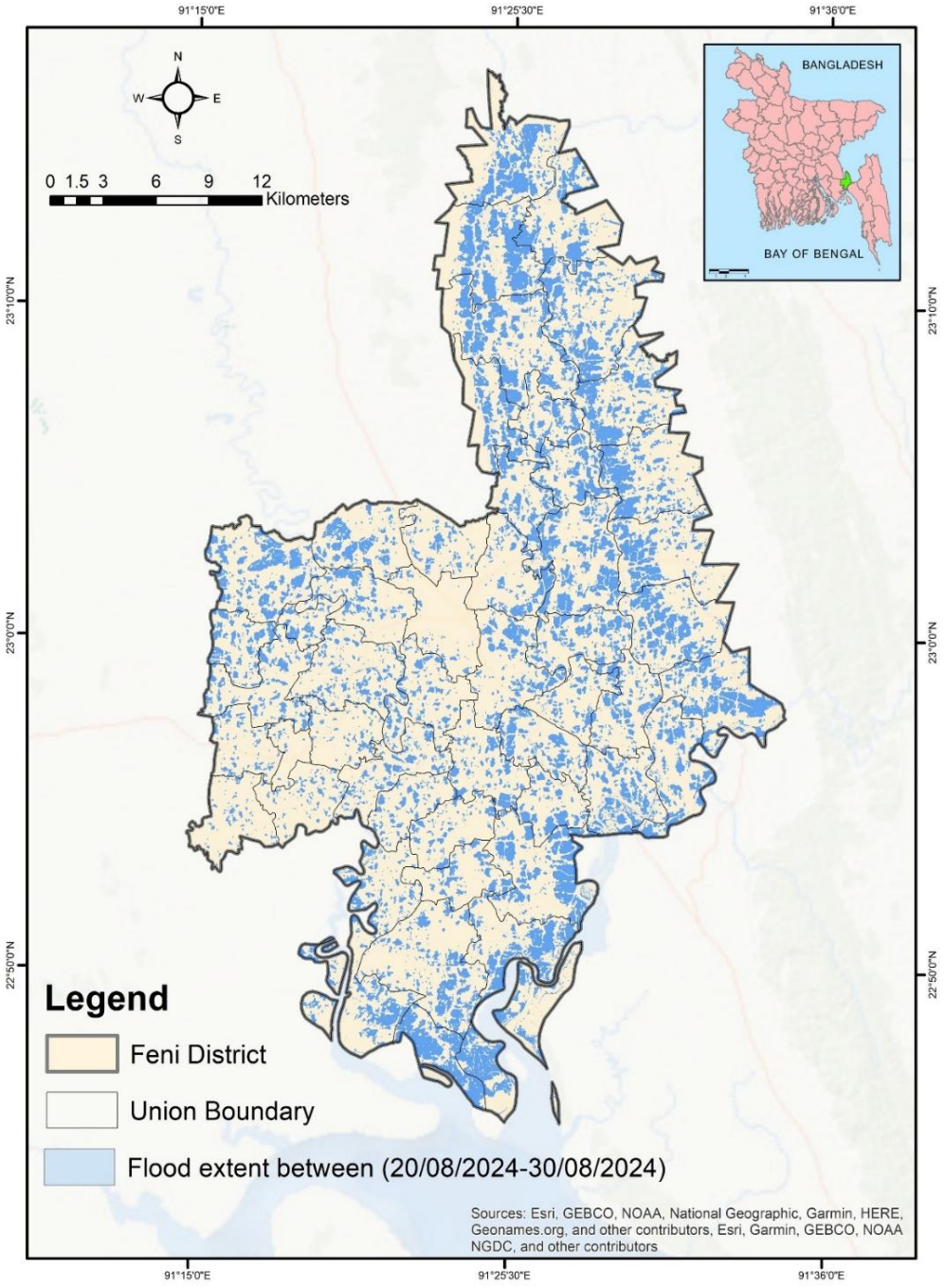


Figure 4.7. Geographic representation of the inundated area, highlighting the flood-prone regions.

This flood extent, which was calculated from satellite data, was the major foundation for defining the locations that were significantly exposed to flash flooding. It was possible to precisely identify flood-affected zones through the incorporation of geospatial data, which also ensured that the selected sites appropriately reflected the flood vulnerability patterns in the Feni district [57].

To ensure spatial representativeness, the sampling sites were distributed across different unions (smallest administrative unit of Bangladesh) within Feni district. These were chosen based on their varying degrees of vulnerability to flash floods, allowing for a comparative analysis of flood vulnerability across different geographic settings (figure 4.8).

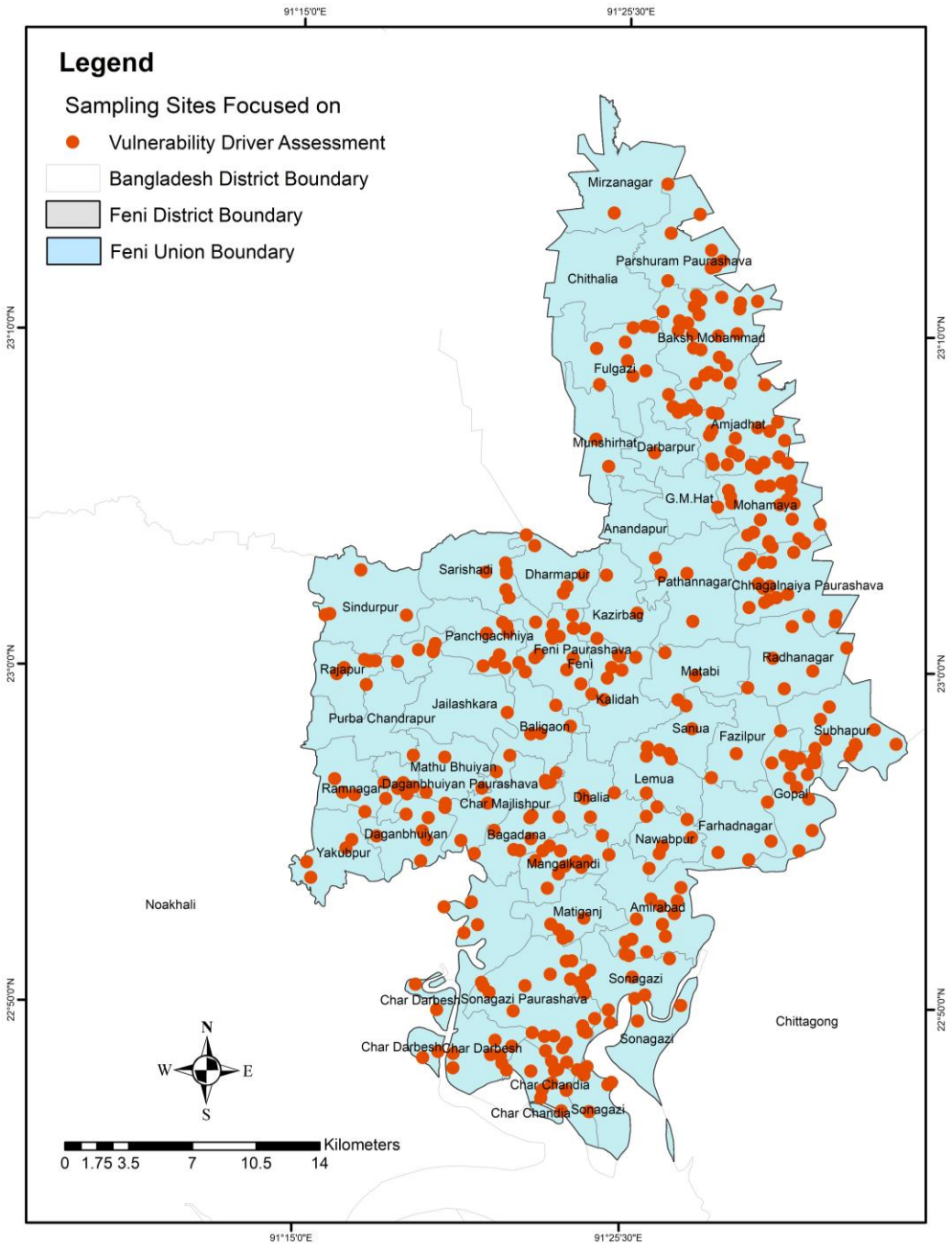


Figure 4.8. Sampling sites, illustrating the selected locations for data collection based on flood extent analysis and vulnerability assessment criteria

Flash floods, which often occur suddenly, made sampling site selection difficult [49]. The sampling sites were also assessed for their representation of economic, social, environmental, and physical vulnerability drivers. Communities with significant unemployment, no financial safety nets, and reliance on agriculture, which is vulnerable to flood damage, were examined for economic vulnerability [85]. Social vulnerability was explored in places with limited flood relief, healthcare, and sanitation services and where social cohesion and community networks-built resilience. Environmental vulnerability was estimated in low-lying floodplains, along riverbanks, or places deforested and losing flood buffers. Settlements with weak infrastructure, housing, and transportation were examined for physical vulnerability [85]. The study was able to understand Feni district's flash flood susceptibility by sampling sites that reflected these varied vulnerability dimensions. Using diverse data sources, rigorous sampling methods, and local knowledge, the study ensured that the selected locations accurately and holistically represented flood-prone populations in Feni district.

4.7 INSTRUMENT FOR DRIVER ASSESSMENT

The assessment of flash flood vulnerability drivers in Feni district was conducted using a structured questionnaire based on a Likert scale. The questionnaire was designed to evaluate multiple dimensions of vulnerability, through a set of statements rated on a five-point scale ranging from "strongly disagree" to "strongly agree." This standardized measurement approach allowed for a nuanced understanding of the severity and perception of vulnerability among affected communities. The Likert scale framework was chosen due to its effectiveness in capturing subjective assessments and enabling quantitative analysis of respondents' perspectives on flood vulnerability [86].

Economic vulnerability drivers were assessed by examining various financial and employment-related factors that influence a community’s ability to

withstand and recover from flash floods (figure 4.9). The survey included questions about the availability of employment opportunities, the prevalence of wage theft, and the accessibility of social safety nets etc. Additionally, respondents were asked about their access to microcredit facilities, insurance coverage, and government financial assistance programs, all of which are crucial in mitigating the financial shocks of recurrent flooding [87].

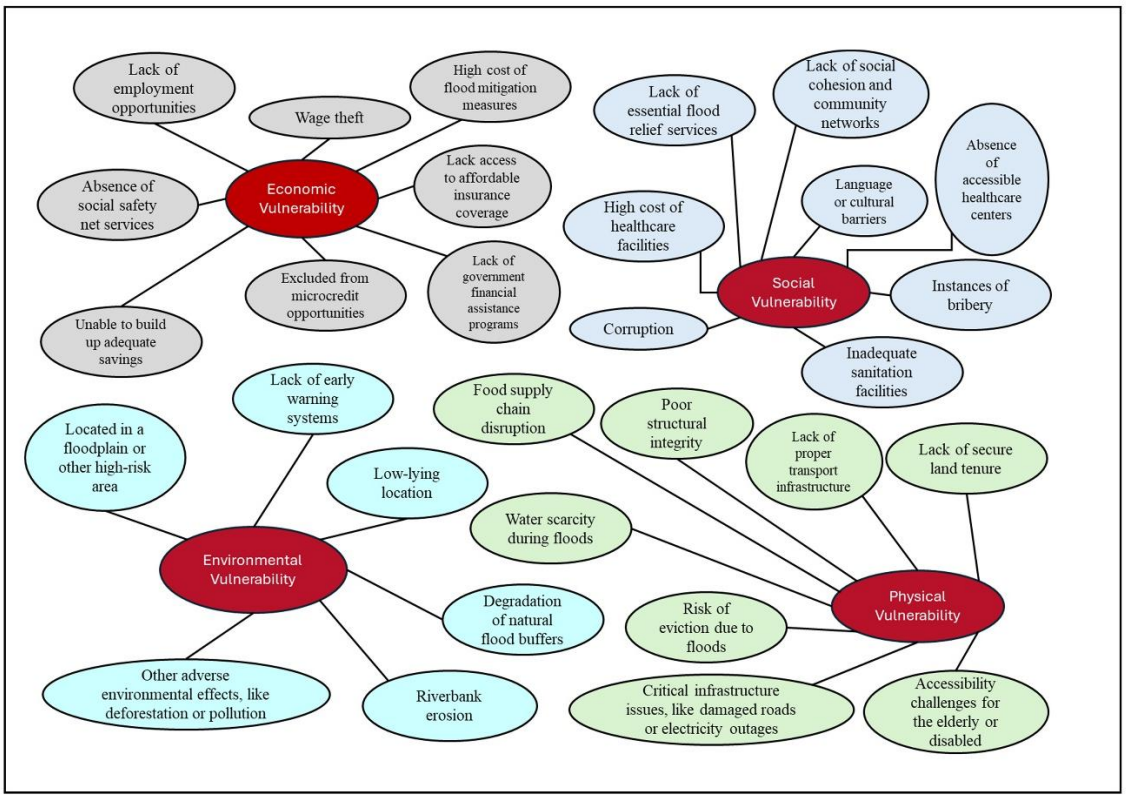


Figure 4.9. Spider Diagram Offering Themes and Drivers of Vulnerability

Social vulnerability drivers were evaluated by exploring issues related to governance, corruption, healthcare access, and community cohesion. Respondents were asked about their experiences with corruption and bribery in local institutions, particularly concerning the equitable distribution of flood relief resources (figure 4.9). The survey also investigated the impact of high healthcare costs and the availability of medical facilities during flood events [88].

Environmental vulnerability drivers were measured by assessing respondents exposure to natural and ecological factors that contribute to flash

flooding (figure 4.9) [88]. The survey included questions about the geographical characteristics of their settlements, such as whether their homes were located in floodplains or low-lying areas (table 4.2). The impact of riverbank erosion on housing stability was also considered, as this phenomenon leads to displacement and loss of property [89]. Respondents were asked whether they perceived environmental degradation, such as deforestation and loss of wetlands, as exacerbating flood risks in their communities. Additionally, the availability and effectiveness of early warning systems were evaluated, as timely flood warnings play a crucial role in reducing flood-related damages [76]. The presence or absence of natural flood buffers, such as mangroves and wetlands, was also assessed to determine how environmental degradation contributes to increased flood exposure.

Table 4.2: Drivers of flash flood vulnerability and their corresponding codes

Vulnerability Dimension	**Code**	**Drivers**	**Vulnerability Dimension**	**Code**	**Drivers**
Economic Vulnerability	Q1	Lack of employment opportunities [90]	Environmental Vulnerability	Q17	Located in a floodplain or other high-risk area [91]
	Q2	Absence of social safety net services [92]		Q18	Lack of early warning systems [91]
	Q3	Unable to build up adequate savings [90]		Q19	Low-lying location [91]
	Q4	Excluded from microcredit opportunities [92]		Q20	Degradation of natural flood buffers [90]
	Q5	Lack access to affordable insurance coverage [92]		Q21	Other adverse environmental effects, like deforestation or pollution [91]
	Q6	High cost of flood mitigation measures [92]			
	Q7	Wage theft [92]		Q22	Riverbank erosion [91]

	Q8	Lack of government financial assistance programs [90]		Q23	Critical infrastructure issues, like damaged roads or electricity outages [93]
Social Vulnerability	Q9	Access to essential flood relief services [94]	Physical Vulnerability	Q24	Risk of eviction due to floods [93]
	Q10	High cost of healthcare facilities [94]		Q25	Water scarcity during floods [93]
	Q11	Corruption [94]		Q26	Food supply chain disruption [93]
	Q12	Instances of bribery [94]		Q27	Poor structural integrity [93]
	Q13	Absence of accessible healthcare centres [90]		Q28	Lack of proper transport infrastructure [93]
	Q14	Inadequate sanitation facilities [94]		Q29	Accessibility challenges for the elderly or disabled [93]
	Q15	Lack of social cohesion and community networks [94]		Q30	Lack of secure land tenure [90]
	Q16	Language or cultural barriers [94]			

Physical vulnerability drivers were examined by focusing on infrastructure, housing conditions, transportation accessibility, and essential services (figure 4.9). The survey assessed whether respondents faced risks of eviction due to floods, as displacement often leads to prolonged instability [73]. The availability of clean water during flood events was another key concern, as water scarcity can result in health crises [74]. Transportation infrastructure was evaluated in terms of its reliability and accessibility during flood events, with a

particular focus on whether damaged infrastructures hinder evacuation and emergency response efforts [95]. The structural integrity of homes was also assessed, as poorly constructed buildings are more likely to collapse or sustain severe damage during floods [95]. Furthermore, respondents were asked whether accessibility challenges existed for vulnerable populations, such as the elderly and disabled, during flood emergencies. Lastly, the study examined disruptions to food supply chains during and after floods, as food security is a critical component of community resilience [76].

A detailed list of the multi-dimensional factors that contribute to flash flood vulnerability is shown in table 4.2, along with the codes (Q1–Q30) that relate to each factor. The questionnaire was carefully designed to capture objective and subjective vulnerability [96].. To collect complete data, trained surveyors interviewed respondents face-to-face. This approach helped clarify questionnaire ambiguities and engage low-literate respondents. To help locals understand the questions, the questionnaire is in English and Bangla (national and local language). To ensure that the findings reflect the experiences of different socio-economic classes, genders, and ages, diverse demographic groups were included.

4.8 SAMPLING PROCEDURE AND SAMPLING SIZE

In this study, for assessing flash flood vulnerability in Feni district, a stratified random sampling approach was employed. The sampling process began with an initial assessment of the flood vulnerability extent, which helped delineate the affected areas. The estimated flood extent forming the basis for determining the survey coverage. The finite population for sample size selection was determined to be 136,268, as estimated using the GHSL 2015 (250m) population density layer [97], by overlying both the flood extent and population density geospatial layer together.

To determine an appropriate sample size for the survey, Cochran's formula was applied [98]. This formula is widely used for estimating sample sizes when dealing with large populations and provides statistically significant results. The formula is:

$$n_0 = \frac{Z^2 \times p \times (1-p)}{e^2} \quad (4.11)$$

Where,

n =Sample size for a large population.

Z =Z-value (the number of standard deviations from the mean). For a 95% confidence level, Z = 1.96.

p =Estimated proportion of the population with the characteristic (assumed to be 0.5 for maximum sample size).

e =Margin of error (typically set at 5%, or 0.05).

Substituting the values: $n_0 = \frac{1.96^2 \times 0.5 \times (1-0.5)}{0.05^2}$ = 384.16. For large populations, the study adjusts this using the finite population correction formula [98]:

$$n = \frac{n_0}{1+\frac{n_0-1}{N}} \quad (4.12)$$

Where,

n_o =385 (calculated above).

N =Total population (136,268).

Substituting values: $n = \frac{385}{1+\frac{385-1}{136268}} \approx 384$. Thus, the final adjusted sample size for the survey is 384.

Given the diverse socio-economic conditions across the flood-affected areas, stratification was employed to distribute the sample proportionally among different vulnerable groups [98]. This ensured representation from various vulnerability background areas. The stratified approach allowed for an in-depth understanding of how different segments of the vulnerable population perceive and experience flood vulnerability [99].

Household surveys were conducted in person. Randomly selecting respondents within each stratified segment avoided bias and ensured that the data reflected the community [99]. The selection criteria included households that had experienced flash floods, ensuring that responses were based on firsthand experiences rather than speculation. This study's structured questionnaire let respondents rate their agreement with multi-dimensional vulnerability statements.

Follow-up was used to reduce non-response bias. Alternative respondents from the same demographic segment were used when selected respondents were unavailable or unwilling. This kept the final dataset representative of the target population. Quality control included cross-checking for inconsistencies and missing values. Data was cleaned before analysis for accuracy and reliability. The study illuminates the complex interactions between multiple flood vulnerability factors by including diverse population segments and geographic representation.

4.9 DRIVING FORCE ANALYSIS

The study systematically interprets the responses collected through the structured Likert scale questionnaire. The study attempted to find underlying patterns, evaluate relationships between several drivers, and provide insights that might guide evidence-based policy recommendations considering the multi-dimensional character of flash flood vulnerability.

Data preparation, where raw survey answers were compiled, arranged, and cleaned for discrepancies was the first phase of the study. Imputation methods were used to handle missing or incomplete answers so that the dataset was complete; outliers were closely investigated to ascertain their validity (figure 4.10, 4.11) [21]. The dataset was then structured into categorical and numerical variables for efficient analysis.

Descriptive statistical techniques were applied to summarize the responses and provide an overall distribution of vulnerability perceptions among

the respondents [100]. For every driver of vulnerability, measures including mean, median, and standard deviation were computed to provide information on overall trends and variances among several vulnerability criteria [49]. Key trends in the dataset were shown using frequency distribution tables and graphical visualizations, so improving the interpretability of the outcomes [101]. Inferential statistical methods were used to investigate the interactions among several vulnerability drivers [102]. Strength and direction of relationships between several facets of vulnerabilities were evaluated using Pearson correlation analysis [34].

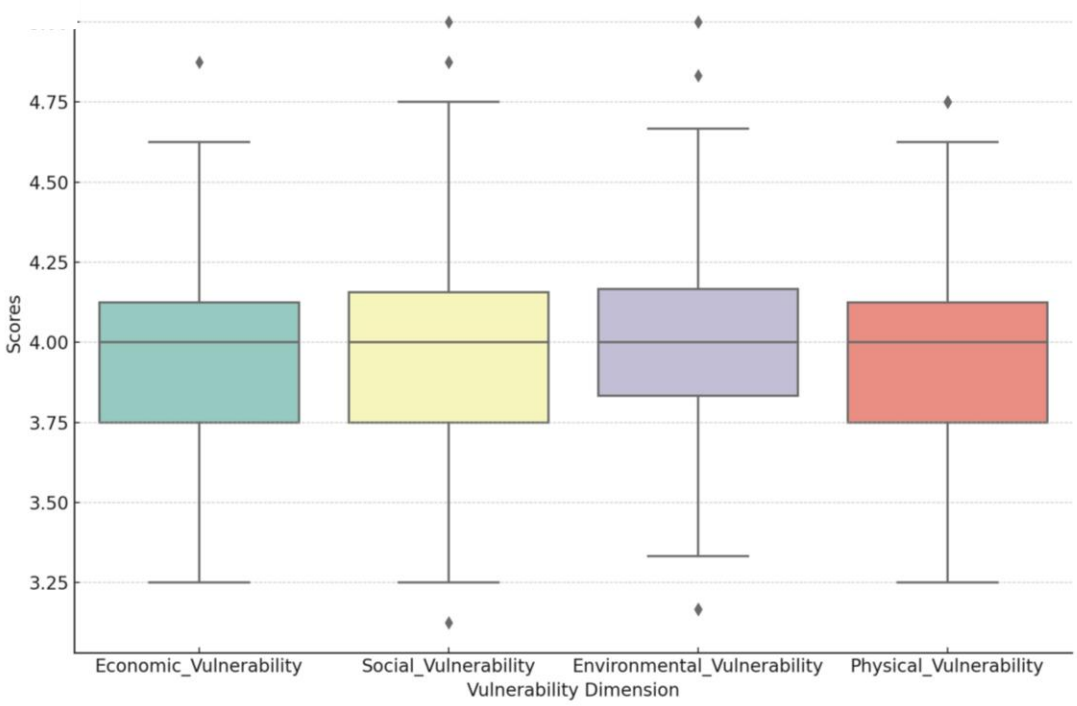


Figure 4.10. Boxplot (average survey response distribution) of the dataset showing the distribution of scores across vulnerability dimensions.

This helped determine whether particular vulnerabilities such as the link between social exclusion and economic instability or between environmental degradation and physical infrastructure challenges were interrelated. Driver analysis was performed to identify underlying latent variables that cluster various vulnerability indicators [47]. The outcomes of factor analysis yielded a

more thorough comprehension of the interactions among various vulnerabilities, facilitating the categorization of communities according to their flood susceptibility.

The results were subsequently analysed in relation to current policy frameworks to discern deficiencies in disaster management strategies, including the National Water Policy 1999, National Water Management Plan 2001, SOD, Disaster Management Act and the Bangladesh Delta Plan 2100, etc. The congruence or incongruence between policy objectives and actual conditions was rigorously analysed to formulate data driven-based recommendations for enhancing flood resilience in the Feni district.

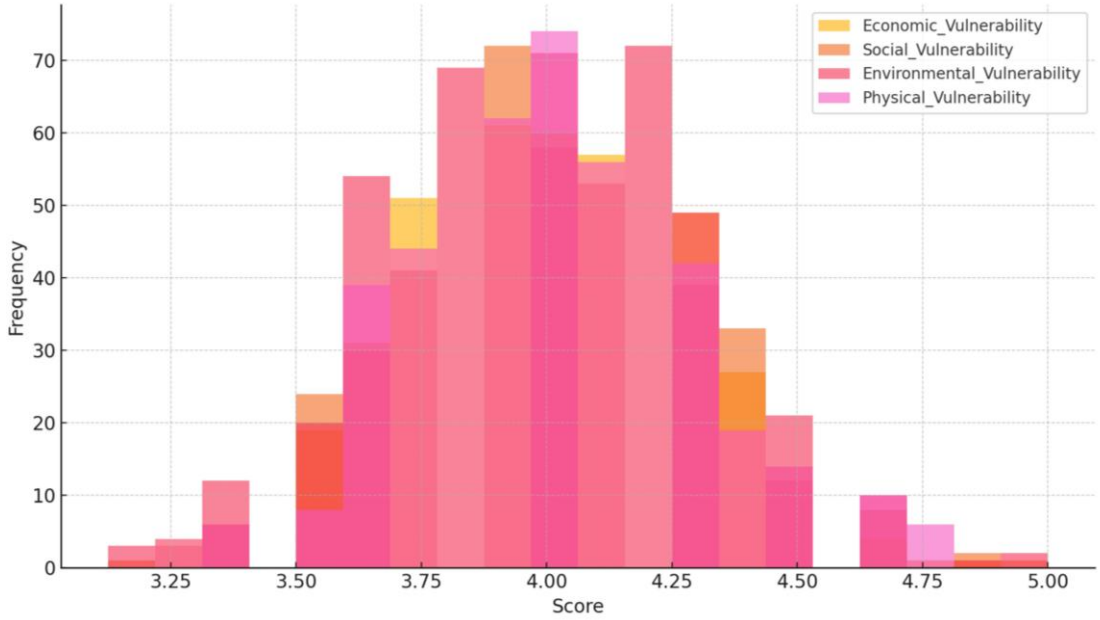


Figure 4.11: Histogram (frequency distribution) of the dataset showing the distribution of scores across vulnerability dimensions.

The integration of statistical, spatial, and qualitative analyses yielded a comprehensive understanding of flash flood vulnerability in the study area. The multi-method approach certain that the findings were both statistically robust and contextually pertinent, aiding in the formulation of comprehensive policy interventions for flood risk mitigation and resilience enhancement.

4.10 SUMMARY

This chapter described the thorough approach used to evaluate the Feni district's vulnerability to flash floods. A description of the study area and the justification for the variables' selection across the physical, social, economic, and environmental dimensions came first. To guarantee consistency, the data were pre-processed and normalized, and strong analytical methods were used to determine the variable weights. Spatial vulnerability maps were created using a flood vulnerability assessment approach based on geographic information systems. The sample plan, location selection, and creation of a systematic questionnaire to evaluate the fundamental causes of vulnerability were also covered in this chapter. Lastly, it provided a thorough overview of the analytical methods employed to evaluate the gathered data, laying a strong basis for the analysis and discussion chapters that followed.

Chapter 5: Vulnerability and Driver Assessment

The study's analytical findings are presented in this chapter, with particular attention to the statistical and spatial evaluations of the Feni district's vulnerability to flash floods. A thorough spatial study of the social, physical, economic, and environmental vulnerability aspects comes after assessing the appropriateness of the chosen data and the weights that were determined. The most vulnerable places are highlighted by hotspot identification and composite vulnerability maps. In order to identify the connections between the various vulnerability types, the chapter also looks into interdimensional comparisons and correlations. The socioeconomic and environmental factors that contribute to flood vulnerability are thoroughly examined, as are their respective intensities and relationship. Additionally, it evaluates national regulations, pinpoints important gaps, and makes tactical suggestions for reducing driving impacts and boosting flood resilience. To guarantee the dependability of the results and suggested frameworks, validation findings are incorporated.

5.1 DATA SUITABILITY AND WEIGHT ASSESSMENT

According to sensitivity and reliability analysis (Table 5.1), the KMO test value exceeded the minimum threshold of 0.6, confirming that the dataset was suitable for PCA. This result indicated that the correlations among variables were strong enough to proceed with the analysis. Similarly, Bartlett's test of sphericity produced a significant result ($p < 0.05$), which validated that the variables in the dataset were sufficiently correlated for PCA.

This made sure that the data displayed significant correlations needed for factor ex-traction. The communalities, calculated as part of the PCA process, demonstrated high values close to 1 for most variables. This indicated that a large proportion of each variable's variance was shared with the others, confirming their strong contribution to the principal components. As a result, the dataset was

deemed statistically appropriate for PCA, and the final weights generated from the analysis were reliable for constructing the vulnerability map.

Table 5.1. Data Adequacy Confirmation Test Result.

Test		Value	Meaning
Kaiser–Meyer–Olkin Sampling Adequacy Measure		0.86	Regarded as good (>0.7). This implies that factor analysis may be performed on the data.
Bartlett's Sphericity Test	Sig.	0.00	Bartlett's Test of Sphericity is significant ($p < 0.001$), demonstrating the presence of correlations in the dataset suitable for factor analysis.

Once the loadings for each indicator were computed, the next step involved squaring these loadings (Equation (4.7)) to quantify the contribution of each indicator in terms of variance explained. To ensure comparability across indicators and dimensions, the squared loadings were normalized (Equation (3.8)). The weights for each indicator in the other dimensions (physical, economic, and environmental) followed similar procedures. The final weights derived through PCA reflect the importance of each indicator and provide a balanced approach to integrating them into the overall flood vulnerability assessment for Feni District (Table 5.2). The final derived weights for each variable allow for the accurate integration of these into the overall vulnerability model to create composite vulnerability maps for each dimension.

Table 5.2. Assigning Weights to Indicators

Factors	Indicators	Variables	Final Weights for Each Criterion
Social Vulnerability	Exposure	Population Density	56.74
		Vulnerable age group	43.26
	Susceptibility	Education	39.42
		Healthcare facility	26.4

		Poverty	34.19
	Resilience	Shelter	100
Physical vulnerability	Exposure	Slope	11.23
		Elevation	20.11
		Land use/landcover	28.32
		Drainage density	13.62
		Geology	17.71
		Soil types	9
	Susceptibility	Previous Flood Extent	100
	Resilience	Access to Roads	100
Environmental Vulnerability	Exposure	Rainfall Intensity	100
	Susceptibility	Urban growth	100
	Resilience	Recovery time to floods	100
Economic vulnerability	Exposure	Urbanized Area	76.45
		Contact with River	23.55
	Susceptibility	Unemployment	100
	Resilience	Recovery time to floods	100

5.2 SPATIAL DISTRIBUTION OF FACTORS BY INTEGRATING VARIABLES

5.2.1 Factors of Social Vulnerability Assessment

The degree to which human populations are at danger during flash flood occurrences is largely determined by social vulnerability [93]. Three main components were used in this study to quantify social vulnerability: exposure,

susceptibility, and resilience. Figure 5.1 shows how these characteristics are distributed spatially within the Feni district.

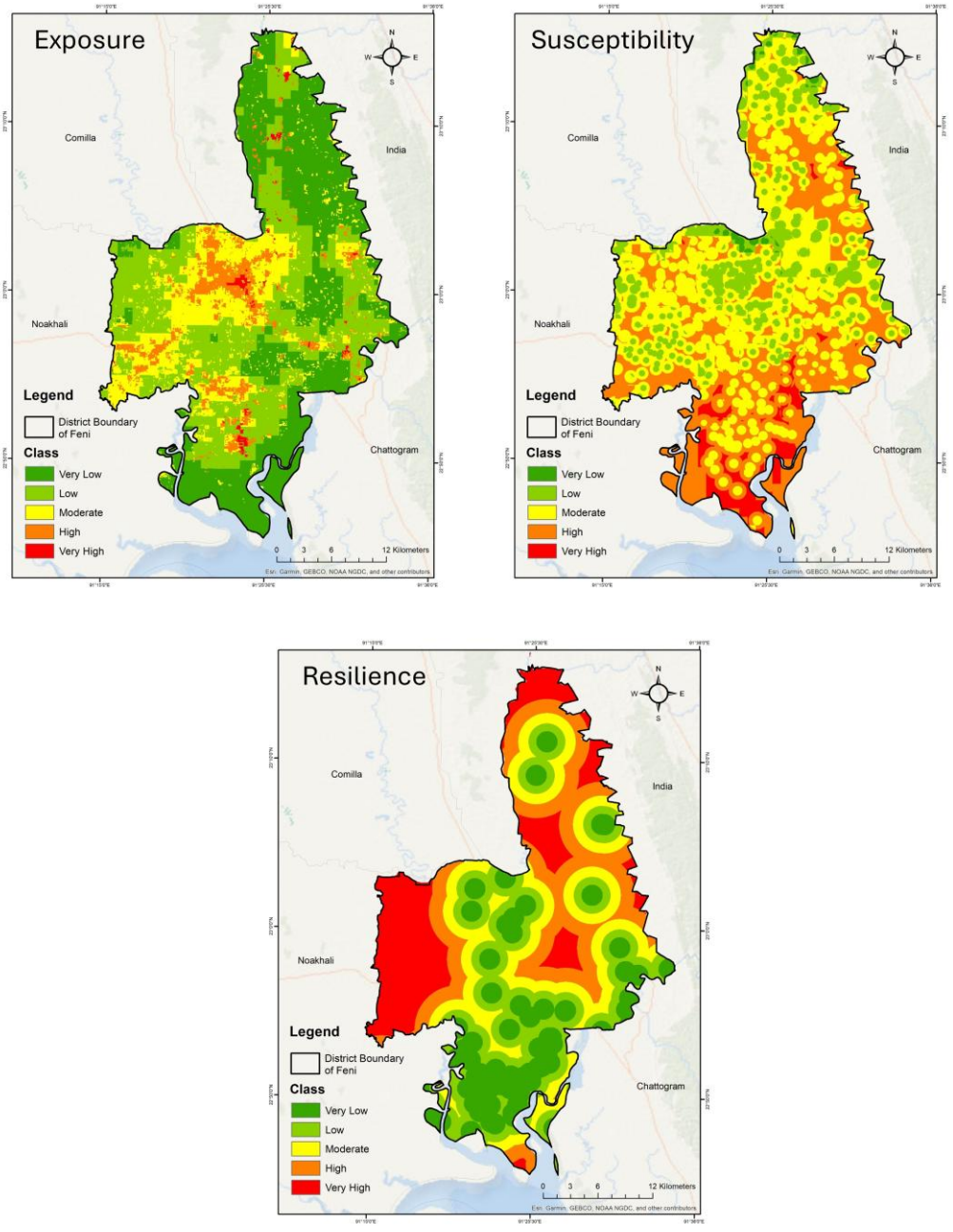


Figure 5.1. Factors of Social Vulnerability: Exposure, Susceptibility and Resilience (from left to right)

The exposure map depicts regional changes in population-related risk variables, particularly population density and vulnerable age groups (children and the elderly). Zones of high to extremely high exposure are mostly found in

the district's centre and southwest, including the neighbourhoods surrounding large communities. Dense populations and a high percentage of age-sensitive groups are characteristics of these areas, which increases their danger of flooding. On the other hand, the district's eastern and southern borders have moderate to extremely low exposure, which is consistent with their sparse population distribution.

The susceptibility layer assesses how much societal factors may intensify the effects of flash floods [2]. The literacy rate, poverty rate, and accessibility to medical services were used to map this. The district's southern and southeast portions, especially those close to the upazilas of Chhagalnaiya and Parshuram, exhibit high to extremely high susceptibility, signifying areas with limited access to healthcare, greater rates of poverty, and lower literacy levels. The middle belt is characterized by moderate sensitivity, whereas the northern regions have substantially lower susceptibility, indicating comparatively greater socio-economic resilience in those regions.

The resilience map exhibits a clear spatial pattern that is influenced by the proximity to cyclone shelters. Extremely low to low resilience is seen in the eastern and southern regions, indicating locations that are remote from emergency shelters, making evacuation and disaster response more difficult. High to very high resilience zones around centre pockets of moderate resilience, especially around central and southeast Feni's well-connected locations where emergency infrastructure is easier to reach.

5.2.2 Factors of Physical Vulnerability Assessment

Topography, geology, land use, and infrastructure are among the geographical factors that are integrated in this evaluation component. As shown in Figure 5.2, the physical vulnerability of the Feni district was assessed using exposure, susceptibility, and resilience.

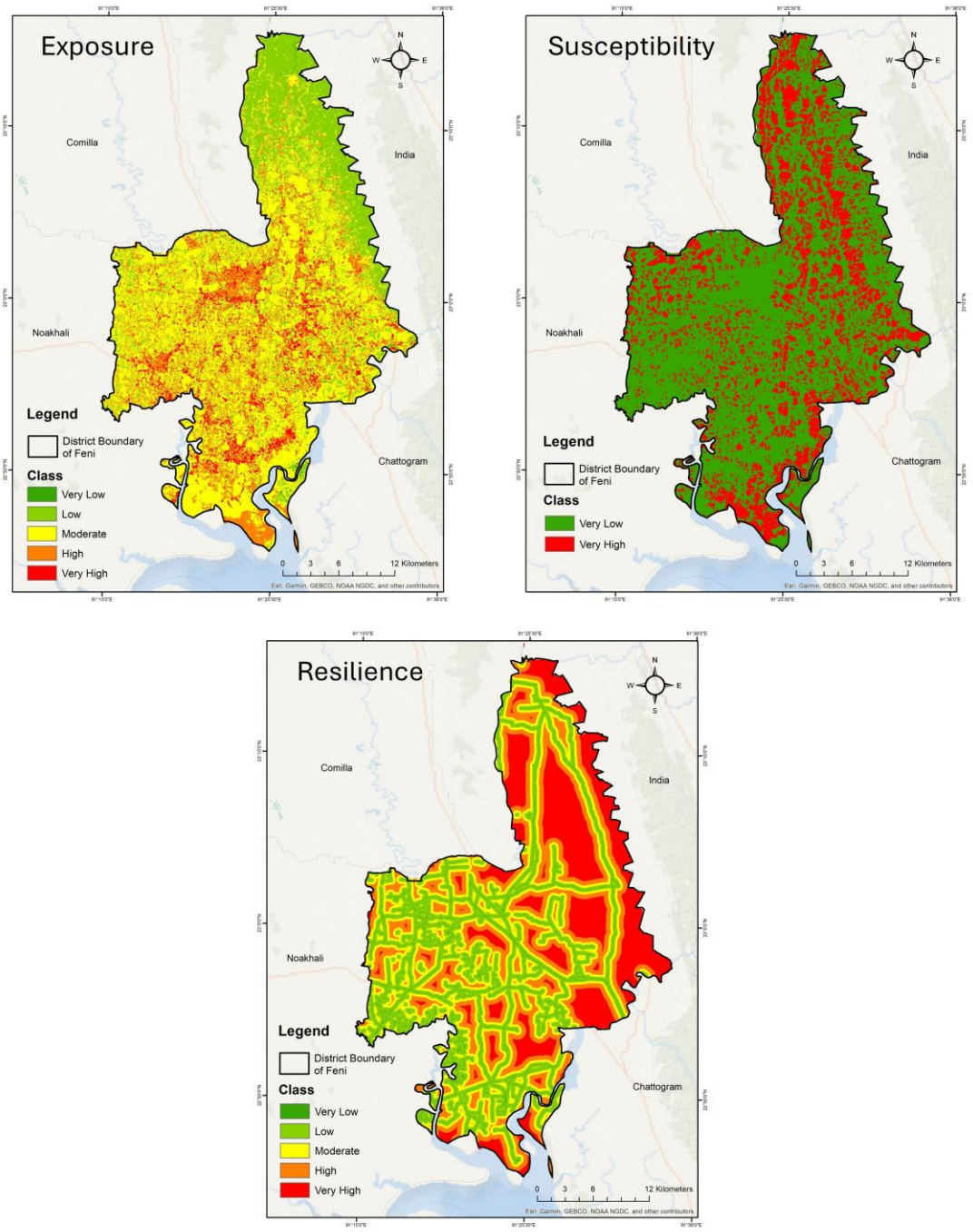


Figure 5.2. Factors of Physical Vulnerability: Exposure, Susceptibility and Resilience (from left to right)

Slope, elevation, drainage density, geology, soil type, and land use and land cover (LULC) are the six biophysical factors that are included in the exposure map. Moderate to very high exposure is found in the central and southeast parts of Feni. These areas are particularly vulnerable to flood

inundation because of their relatively low elevation, denser drainage networks, and land use patterns that are dominated by farmland and settlements. Due to higher elevation, less extensive drainage systems, and more stable soil types and geological formations, the district's northern and northeastern regions, on the other hand, show low to extremely low exposure.

Susceptibility was estimated using historical flood extent, which represents places that have previously been flooded. A clear bipolar distribution can be seen on the susceptibility map. A sizable section of the centre, southern, and southeast regions exhibit extremely high vulnerability, suggesting that flooding has historically occurred frequently or severely in these locations. Very low susceptibility is seen in the northern and northwest regions, suggesting that there have been few previous floods or that they have been less exposed to previous events. Because it offers a trustworthy indicator of future flood hazards, this pattern emphasizes how crucial it is to incorporate past flood data into physical vulnerability evaluations.

Road accessibility is a sign of resilience, indicating a community's capacity to evacuate or receive assistance both during and after a flood catastrophe. Road-accessible regions (shown in green and yellow on the resilience map) form a web-like network throughout the district, indicating zones of moderate to high resilience. The southern, eastern, and southeast Feni peripheries, on the other hand, have widespread low to very low resilience, which is indicative of areas with remote topography or little access to roads. This implies that poor road infrastructure increases vulnerability even in areas with high exposure and sensitivity, especially during a flash flood.

5.2.3 Factors of Economic Vulnerability Assessment

Economic vulnerability is the degree to which local economic systems and livelihoods are susceptible to the risks of flash floods [103]. Figure 5.3 shows the three categories of exposure, susceptibility, and resilience that were used to

examine economic vulnerability in the Feni district using geographical indicators.

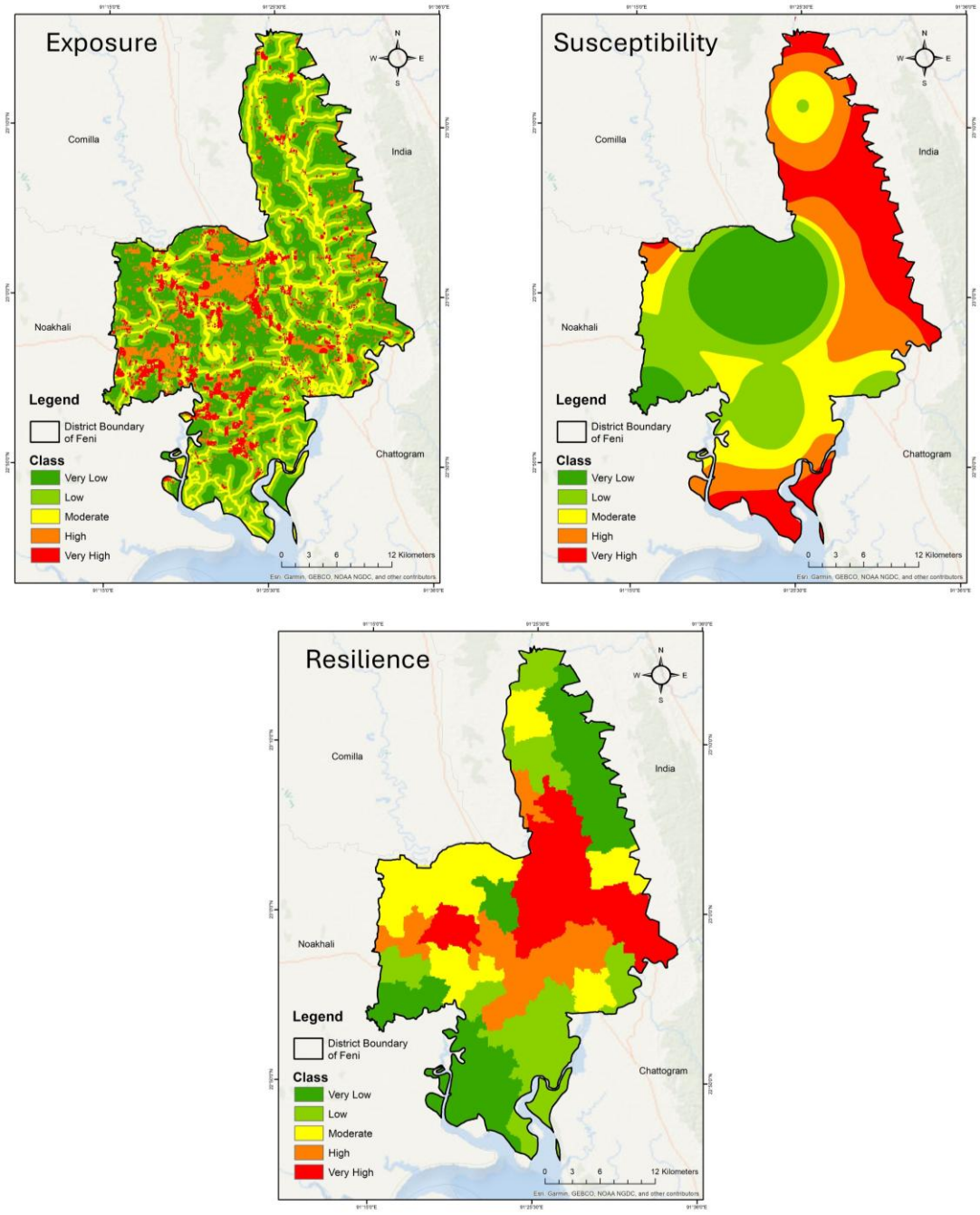


Figure 5.3. Factors of Economic Vulnerability: Exposure, Susceptibility and Resilience (from left to right)

Economic exposure takes into account regions that are more vulnerable to floods and have a concentration of commercial activity. Exposure was mapped

using two variables: contact with the river and urbanized area. Clusters of high to extremely high exposure are primarily found in the central and southwestern regions of Feni, according to the exposure map. Due to their near proximity to river networks and greater concentration of urbanized zones, these locations are more vulnerable to the effects of flooding. Low to extremely low exposure is shown in the northern and southeast regions, suggesting that these areas are comparatively rural, less developed, and have few economic resources that are directly vulnerable to flooding. The concentration of economic vulnerability in more developed urban areas that also cross with hydrologically vulnerable zones is shown by this spatial pattern.

Economic susceptibility was evaluated using unemployment rates, which serve as a stand-in for economic fragility and diminished recovery potential. The susceptibility map reveals a sharp disparity: high to extremely high susceptibility indicates widespread unemployment or underemployment in the district's eastern and northern parts. Southern and southwestern regions, on the other hand, show low to extremely low susceptibility, presumably as a result of their more advanced infrastructure, job possibilities, and economic diversification. This implies that, in contrast to the economically vulnerable northern regions, the southern regions may have a comparatively stronger economic basis to withstand interruptions caused by flooding, despite their greater vulnerability.

Economic resilience is measured by the variable recovery time to flood, which indicates how quickly towns may restart economic activity following flood disasters. There is a diverse spatial pattern on the resilience map. The district's southern and partly northwest regions contain a number of areas with very high to high resilience. The central and eastern regions, on the other hand, indicate low to extremely low resilience, which is consistent with zones that are also very susceptible.

5.2.4 Factors of Environmental Vulnerability Assessment

The central and eastern regions of the Feni district are particularly vulnerable to heavy rainfall, according to figure 5.4, which shows the spatial distribution of rainfall intensity as a direct exposure factor. Areas that get significant precipitation during the monsoon season are indicated by red and orange zones, which indicate high to extremely high exposure levels. Low to moderate exposure is seen in the district's southern and southwestern regions, which are represented by the green to yellow classes.

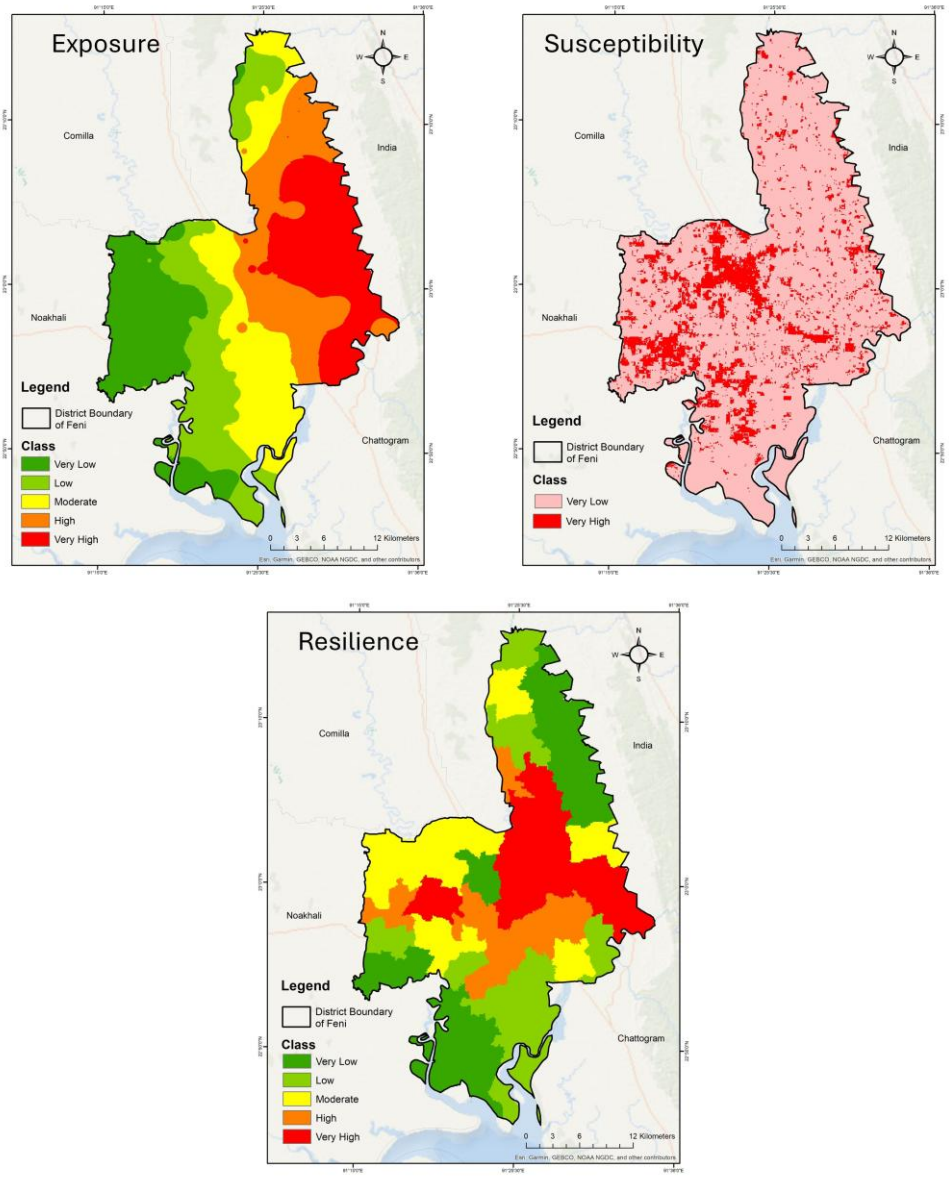


Figure 5.4: Factors of Environmental Vulnerability: Exposure, Susceptibility and Resilience (from left to right)

The figure 5.4 shows that a significant section of the district is coloured in red, suggesting very high susceptibility, especially in areas that are heavily populated and quickly urbanizing. This pattern indicates that the likelihood of flash floods in these areas is being exacerbated by unplanned or rapid urban expansion that is encroaching on natural drainage pathways and increasing surface runoff.

Resilience varies throughout the district, as evidenced by the estimated recovery time following severe flooding. The green-shaded southern and southwestern regions show strong resilience. On the other hand, the red and orange central and eastern regions exhibit low to very low resilience, meaning that they recover from floods more slowly. Poor accessibility, a lack of suitable flood recovery methods, or a larger population density that slows rehabilitation could all be contributing factors to this delay.

5.3 SPATIAL DISTRIBUTION OF FLASH FLOOD VULNERABILITY

The spatial distribution of vulnerability in different dimensions for flash flooding in the Feni district highlights significant spatial variations across different vulnerability dimensions (Figure 5.5). These vulnerabilities have been classified into five categories: very low, low, moderate, high, and very high, offering a detailed understanding of how different unions (total 48) are impacted by flash floods (Figure 5.6).

The social vulnerability map (Figure 4.5a) and union breakdown (Figure 5.6a) reveal substantial differences in how unions are vulnerable to flash floods. In terms of very low social vulnerability, five unions stand out, with Mirzanagar showing the highest percent-age (87.54%) of area classified as of very low vulnerability, followed by Sindurpur (73.23%), Purba Chandrapur (72.89%), Rajapur (71.07%), and Darbarpur (70.15%). These unions are relatively less at risk in terms of social dimension. Conversely, high vulnerability areas include

Nawabpur (41.66%) and Dharmapur (37.21%), with Nawabpur appearing again in the very high vulnerability category (42.60%), alongside Mangalkandi (54.47%) and Sonagazi Paurashava (54.05%).

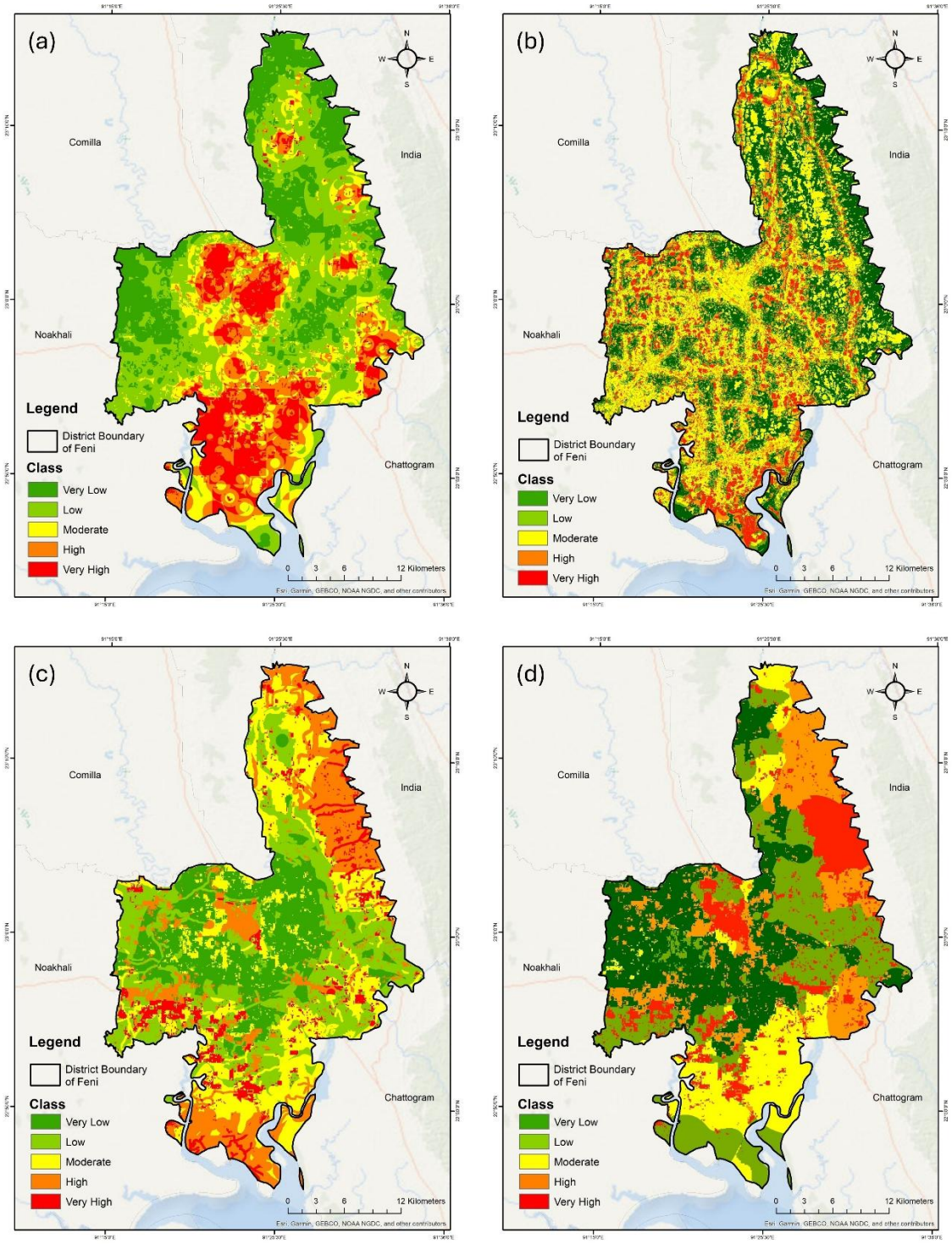


Figure 5.5. Spatial Analysis of Vulnerability in Feni District, Bangladesh: (a) Social Vulnerability, (b) Physical Vulnerability, (c) Economic Vulnerability, (d) Environmental Vulnerability.

The physical vulnerability map (Figure 5.5b) and corresponding union analysis (Figure 5.6b) suggest a wide range of physical risks from flash floods. Mohamaya ranks highest for very low physical vulnerability with 55.22% of the area classified as such, followed by Amjadhat (54.86%), Baksh Mohammad (49.79%), and Subhapur (48.92%). These areas are less prone to physical infrastructure damage from flash flooding. However, moderate and high vulnerability levels are significantly seen in unions like Yakubpur (58.64%) and Char Chandia (51.92%), while Char Chandia also ranks highest for very high vulnerability, with 15.59% of its area classified under this risk category.

Economic vulnerability (Figure 5.6c) is distributed across various unions, with some regions being more economically vulnerable than others. Baligaon leads, with 78.65% of its area showing very low vulnerability, suggesting that the economic impact of flash floods would be relatively minimal. Similarly, Kazirbag (74.82%) and Kalidah (72.04%) follow closely behind in this category. For higher vulnerability classes, unions like Amjadhat (80.61%) and Mohamaya (76.20%) are classified as highly vulnerable in terms of economic loss, reflecting significant risks to local economies during flash floods. Char Chandia stands out, with 33.10% of its area classified as of very high economic vulnerability, underscoring the financial risks posed by recurrent flooding.

Environmental vulnerability (Figure 5.6d) presents another crucial aspect of the study. Dhalia, with 86.86% of its area categorized as of very low vulnerability, emerges as one of the least environmentally vulnerable unions. Similar trends are seen in Purba Chandrapur (86.46%) and Rajapur (84.64%). At the higher end of the spectrum, Mohamaya is almost entirely categorized as very highly vulnerable, with 99.31% of its area under severe environmental threat. Amjadhat (79.02%) and Feni Paurashava (68.92%) also fall into this high-risk category, indicating areas where flash floods severely impact environmental stability.

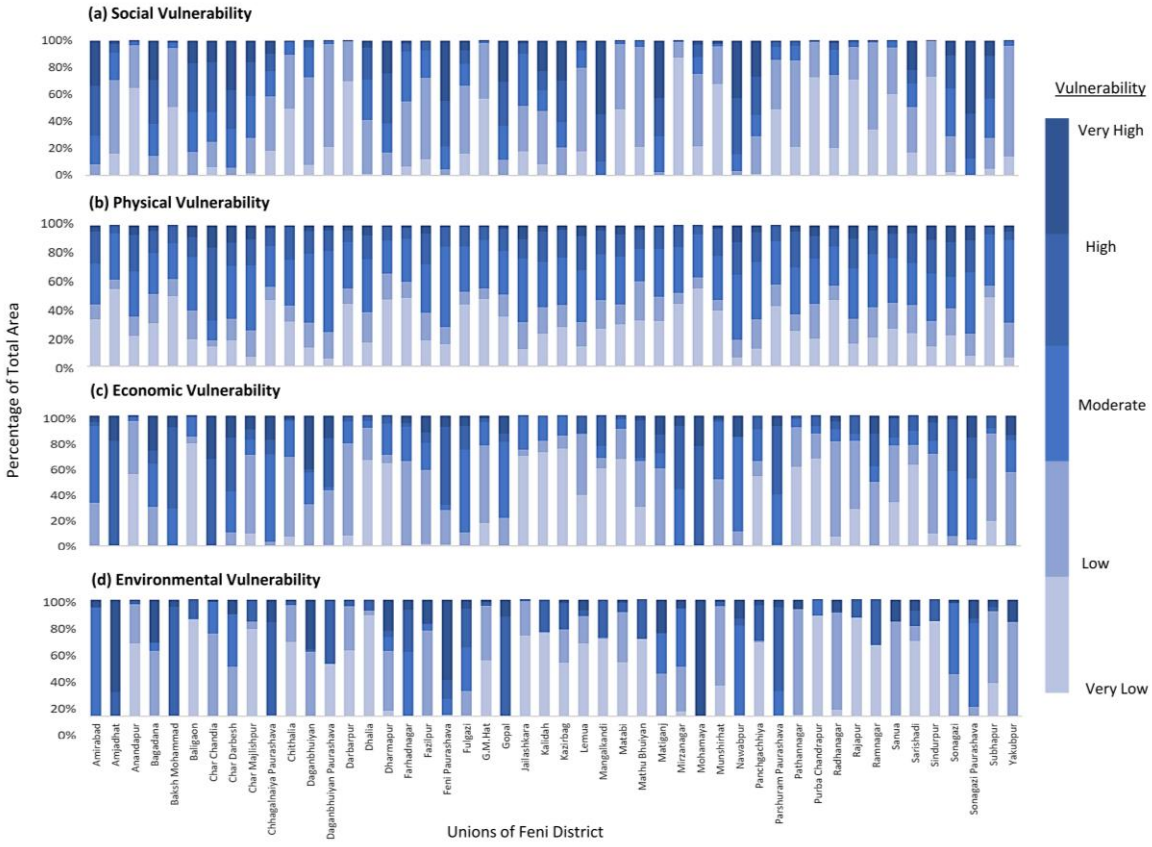


Figure 5.6. Union-Wise Breakdown of Vulnerability in Feni District, Bangladesh: (a) Social Vulnerability, (b) Physical Vulnerability, (c) Economic Vulnerability, (d) Environmental Vulnerability.

The vulnerability to flash floods in the Feni district varies significantly across social, physical, economic, and environmental dimensions. The spatial distribution of vulnerability highlights critical areas that require targeted interventions to mitigate the risks posed by flash floods. Unions like Char Chandia and Nawabpur exhibit high vulnerability across multiple dimensions, while areas like Mirzanagar and Baligaon show relatively lower risks. This detailed vulnerability mapping offers a foundational basis for disaster management strategies aimed at reducing the impact of flash floods in Feni district.

5.4 COMPOSITE FLASH FLOOD VULNERABILITY

The composite vulnerability map for Feni District integrates the four dimensions of vulnerability into a single, comprehensive assessment of flash flood vulnerability.

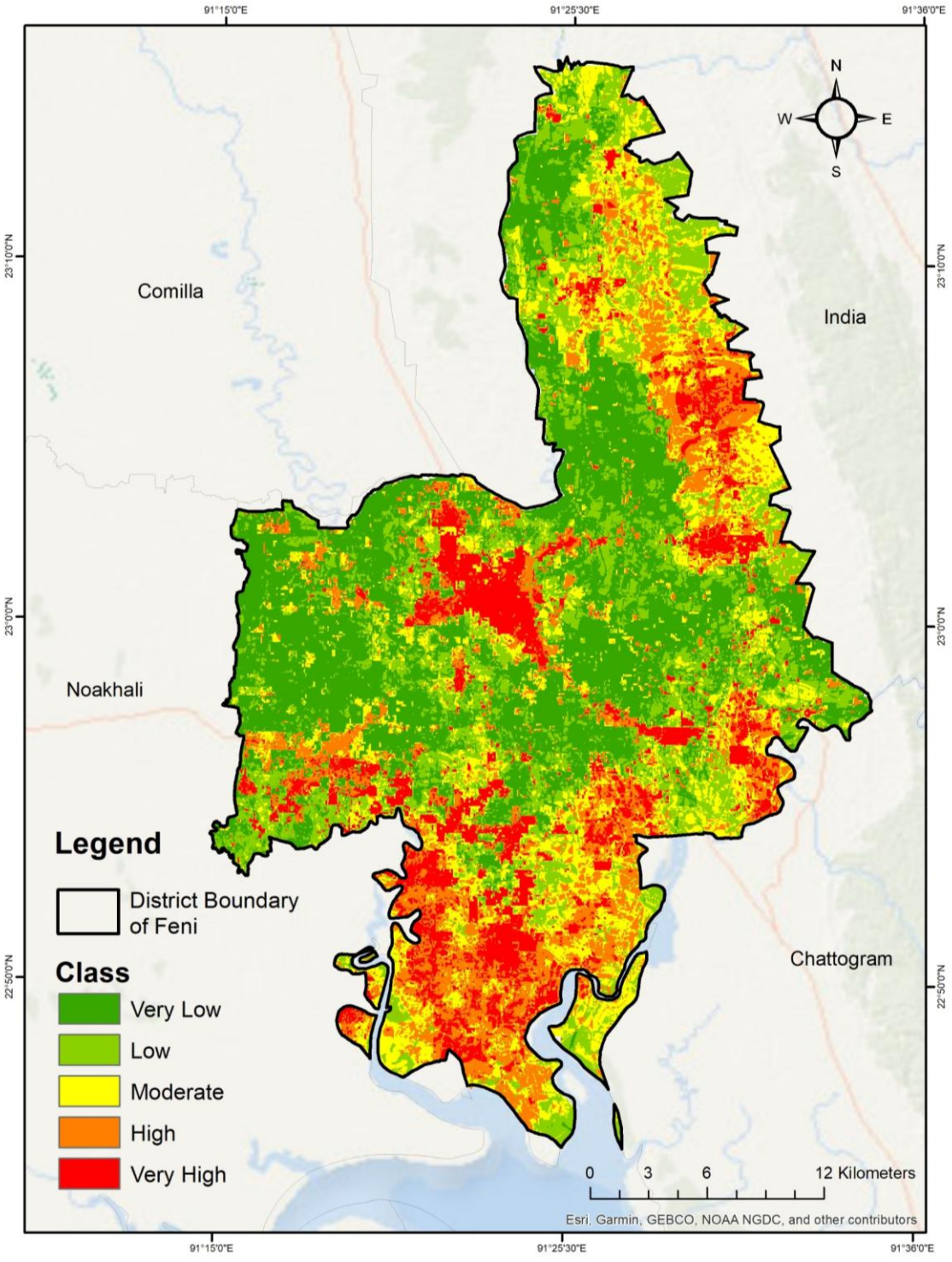


Figure 5.7. Composite vulnerability map for Feni District.

This map in Figure 5.7 illustrates the overall spatial distribution of vulnerability across the district, categorizing each region into five vulnerability classes. It provides an overview of areas at greatest vulnerability from flash floods, helping to guide disaster preparedness and response efforts.

Based on the results, approximately 30.19% of the district falls under the "very low" vulnerability category, reflecting areas with favourable physical, social, economic, and environmental conditions that reduce their susceptibility to floods. Around 22.21% of the district has "low" vulnerability, indicating relatively stable conditions but still some exposure to flood risks. Regions classified as having "moderate" vulnerability represent 18.35% of the district, while 17.26% of the area is considered to be at "high" risk. Finally, 11.99% of the district falls into the "very high" vulnerability category, highlighting regions where all four dimensions of vulnerability converge to create significant flood risks.

5.5 ASSESSMENT OF VULNERABILITY HOTSPOTS

The integration of all four vulnerability dimensions highlights several key vulnerability hotspots within the Feni District that demand immediate attention. According to Figure 5.8, regions such as Bagadana, Sonagazi, and Nawabpur stand out, with substantial portions of their areas classified under "high" or "very high" vulnerability. For example, Bagadana shows a concerning 30.14% of its area classified as of "very high" vulnerability, signalling a significant vulnerability due to socio-economic and physical factors, such as low elevation and a lack of adequate flood defence infrastructure. Similarly, Sonagazi Paurashava faces extreme risks with 45.45% of its area classified as "high" vulnerability, along with an additional 39.96% categorized as "very high." This combination of physical and economic challenges increases the area's exposure to flood-related damages.

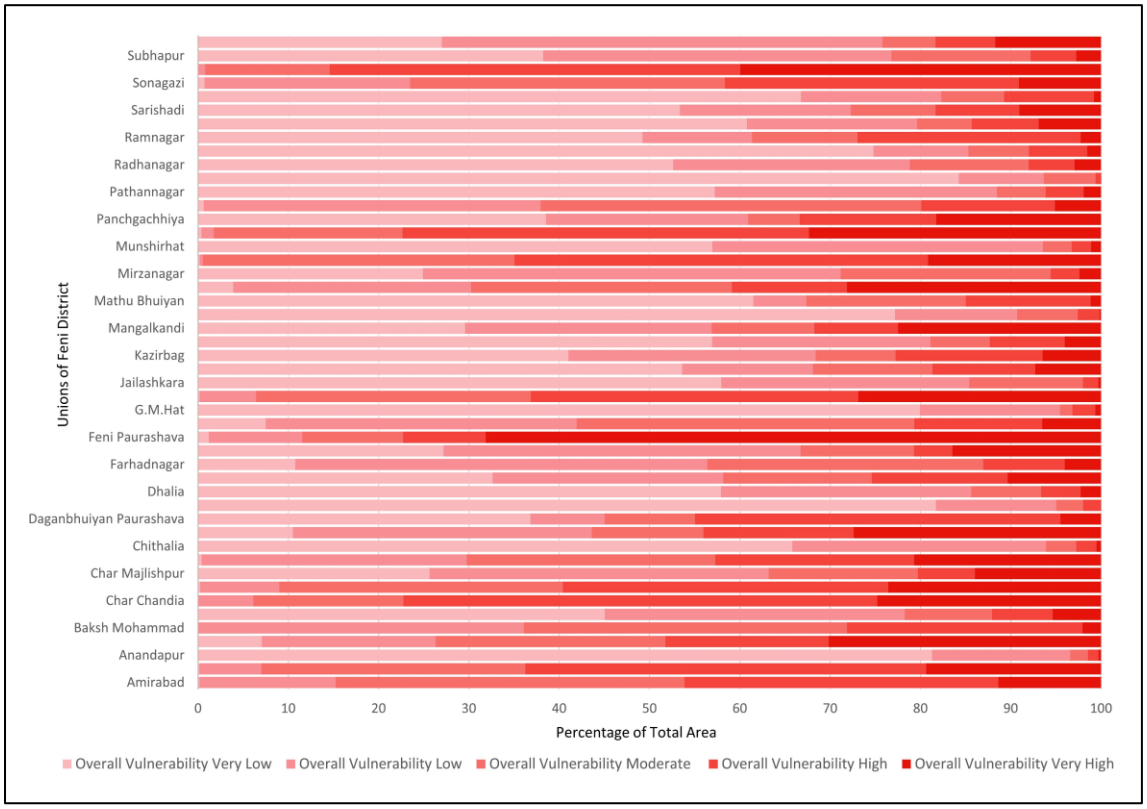


Figure 5.8. Union wise distribution of the overall flash flood vulnerability for Feni District.

On the other hand, areas such as Anandapur emerge as significantly less vulnerable, with 81.29% of its region falling under the "very low" vulnerability classification. This was due to its favourable physical characteristics, having a higher elevation and low population density, complemented with more robust social and economic structures.

Overall, Sonagazi Paurashava, Bagadana, Feni Sadar, and Nawabpur have been marked as zones of high vulnerability emanating from high exposure levels to flash floods. These areas need to be given maximum priority in planning flood mitigation and disaster preparedness programs in order to reduce impacts.

5.6 COMPARISON OF VULNERABILITY ACROSS DIMENSIONS

When vulnerability is compared across the four dimensions, it becomes clear that various factors influence different sections of the Feni District. Social

vulnerability pre-dominates in certain contexts, whereas environmental or physical elements are more important in others.

In the case of Feni Sadar, one of the main causes of overall vulnerability is social vulnerability, which is caused by very high population density and higher population com-position of the most vulnerable age groups. This is further aggravated by the economic vulnerability caused by high urbanization and the dominance of commercial as well as infrastructural developments in the area. There are also other physical causes, such as low altitude and inadequate drainage, which further increase the flood risk in this region.

On the other hand, in the union of Amirabad, physical vulnerability is less important but the economic environmental vulnerability is high, especially for urbanization and rainfall, so types of vulnerabilities are differently distributed. This indicates that there should be a focus on specific measures that will reduce the risks that come from the unique vulnerabilities of the region.

These dimensions of comparative vulnerability highlight the need for a more com-prehensive approach to flood risk management. Economically and socially vulnerable regions, such as Feni Sadar and Sonagazi, should not only be supplied with infrastructural enhancements, but also with programs that will help manage the populations in these high-risk areas and improve communities, rather than just build walls to cage them in. On the contrary, regions such as Amirabad, where environment and physical aspects are the leading causes of vulnerability, need to focus on putting in place better water and land policies to control flooding effects. To sum up, the composite vulnerability assessment more comprehensively explains the flood risk in Feni District, focusing on the suitability of flood preparedness measures that respond to the vulnerabilities of specific regions within the district.

5.7 CORRELATION BETWEEN VULNERABILITY DIMENSIONS

An in-depth statistical examination of the interdependence of social, physical, economic, and environmental vulnerabilities shows interesting aspects that enhance overall vulnerability (Figure 5.9).

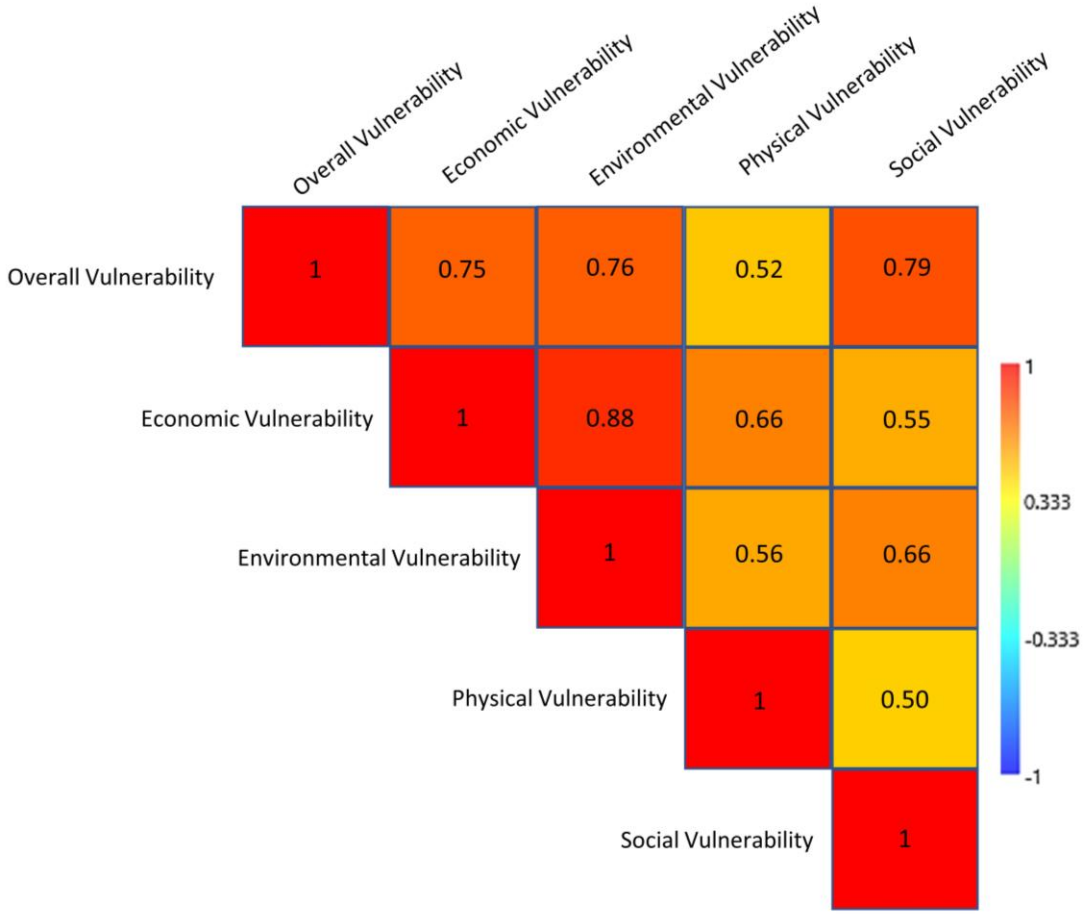


Figure 5.9. Correlation between overall vulnerability and its dimensions.

This study applied Pearson's correlation coefficient (r), a statistical method, based on the linear relationship existing between the stated dimensions, taking values over the range −1 to 1, whereby 1 is a complete positive correlation, −1 is a total inversion correlation, while 0 means there is no relationship [30].

Figure 5.9 shows multiple strong relationships between dimensions. These correlations offer insightful information on the ways in which various dimensions interact to affect the district's overall flood vulnerability. Overall vulnerability has strong positive correlations with most dimensions. The highest

value of correlation coefficient between overall vulnerability and social vulnerability is 0.79. It can be inferred that the driving elements of Feni District's overall flood vulnerability are predominantly social factors. Eco-nomic vulnerability also strongly correlates with overall vulnerability, with a coefficient of 0.75, which specifies that regions with high economic vulnerability face increased severity of impacts in the case of a flash flood. Similarly, the strong positive value for environmental vulnerability and overall vulnerability is 0.76. This evidence points to environmental influences as key determinants in setting an overall level of vulnerability within the district. Physical vulnerability correlations are more modest at 0.52, indicating that physical factors, though important, may be mitigated somewhat in certain areas by social and eco-nomic resilience.

Economic vulnerability is strongly correlated with environmental vulnerability at a coefficient of 0.88, which confirms that, indeed, regions with high economic risk, for in-stance, unemployment and rapid urbanization, tend to be more environmentally challenged, particularly those in areas with the highest rainfall, along with rapidly urbanizing areas. There are also moderate associations of economic vulnerability with both physical (0.66) and social vulnerability (0.55), underlining the interrelatedness of infrastructure is-sues, poor drainage, and low elevation in relation to socio-economic concerns, such as health care access and education. Similarly, environmental vulnerability also correlates strongly with economic vulnerability at 0.88 and is moderately related to physical vulnerability at 0.56, showing that those areas with poor drainage and generally low-lying topography carry both economic and environmental risk. It is also moderately correlated with social vulnerability, at 0.66. Physical vulnerability is strongly related to economic vulnerability, at 0.66, and to environmental vulnerability, at 0.56, but less so in the case of social vulnerability, at 0.50. Among these factors, social vulnerability is highly correlated with overall vulnerability and environmental vulnerability, whereas it is moderately cor-

related with economic vulnerability and is poorly correlated with physical vulnerability.

5.8 MULTI-DIMENSIONAL VULNERABILITY DRIVER ASSESSMENT

5.8.1 Economic vulnerability

From the survey results, the study found that the average ratings for the economic vulnerability drivers in figure 5.10. To fully grasp the elements that enhance economical vulnerability during flash floods, it is essential to examine the graph, which sheds light on the relative importance of each driver.

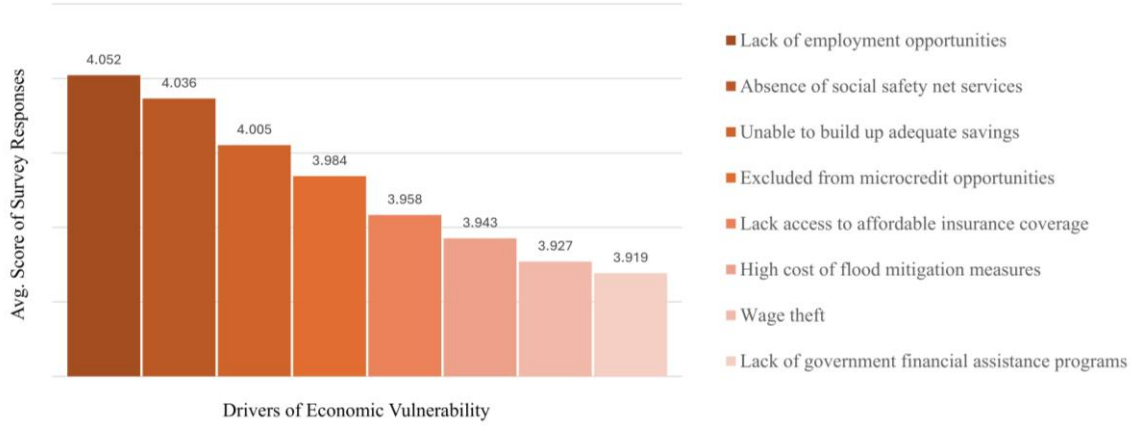


Figure 5.10: Average scores of economic vulnerability drivers.

The figure 5.10 shows that the most important source of economic vulnerability is the lack of employment opportunities, with the highest average score of 4.75. Next on the list with an average score of 4.50 is the lack of social safety net services. The absence of government financial assistance programs (4.00) and the high cost of flood mitigation measures (4.25) are two more causes that have a significant influence. On the other hand, average scores of 3.75 for wage theft and 3.50 for insufficient savings indicate that these factors contribute to economic vulnerability to a lesser extent, although they are nonetheless essential.

5.8.2 Social vulnerability

Figure 5.11 shows the average scores of the drivers of social vulnerability. In order to determine the primary elements that contribute to societal vulnerability in the context of flash floods in the Feni District, it is vital to have a clear picture of the relative severity of each driver [57].

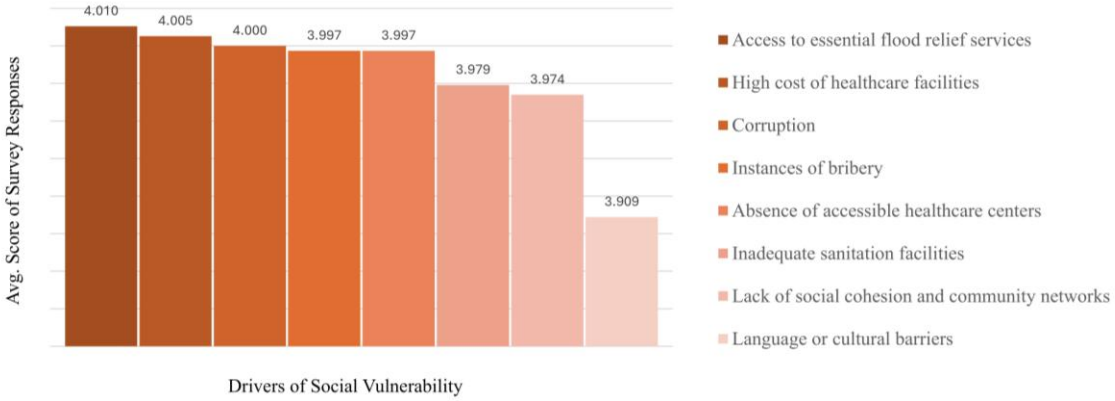


Figure 5.11. Average scores of social vulnerability drivers.

In figure 5.11, it indicates that the elevated expense of healthcare facilities has the highest average score of 4.01, signifying it is regarded as the most substantial factor contributing to social vulnerability. The lack of accessible healthcare centers is carefully tracked, with an average score of 4.01. Additional factors, including insufficient sanitary facilities (3.99) and a deficiency in social cohesiveness and community networks (3.99), also have significant influence. Conversely, linguistic or cultural obstacles and occurrences of bribery have somewhat lower average scores of 3.95 and 3.94, respectively, indicating they are comparatively less significant but nonetheless relevant factors in social vulnerability. These results underscore the pressing need to prioritize healthcare accessibility and affordability in order to mitigate social vulnerability. This provides a solid foundation for formulating specific suggestions to alleviate the socioeconomic consequences of flash floods in the area.

5.8.3 Environmental vulnerability

Figure 5.12 shows the average scores of the factors contributing to environmental vulnerability, based on the survey results. It shows the comparative severity of each environmental vulnerability driver, which is essential for comprehending the primary variables leading to flash floods in Feni District.

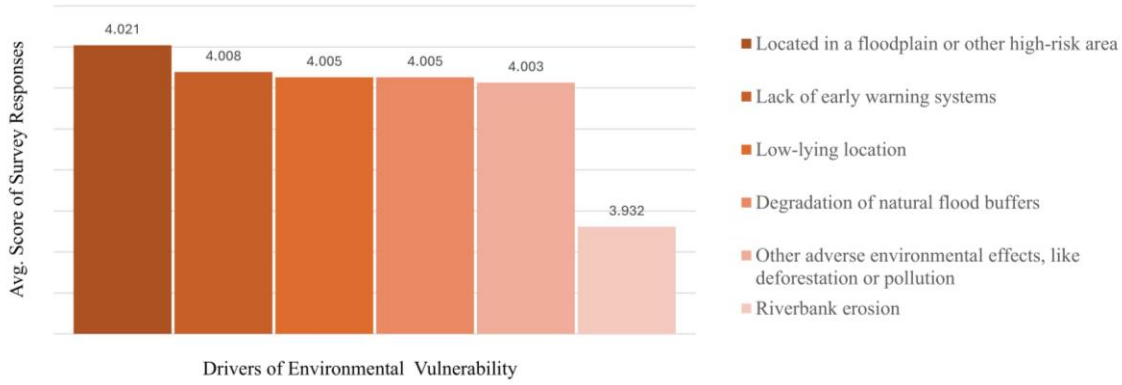


Figure 5.12. Average scores of environmental vulnerability drivers.

Figure 5.12 indicates that residing in a floodplain or other high-risk location has the highest average score of 4.02, signifying it is regarded as the most critical factor contributing to environmental vulnerability. The absence of early warning systems is closely associated, with an average score of 4.01. Additional factors, including the deterioration of natural flood buffers (4.01) and riverbank erosion (4.0), also demonstrate significant effects. Conversely, low-lying locations and other detrimental environmental factors, such as deforestation and pollution, have somewhat lower average scores of 3.99 and 3.98, respectively, indicating they are comparatively less significant but still major contributors to environmental vulnerability. These results underscore the pressing need to tackle spatial hazards and the lack of early warning systems as critical priorities for mitigating environmental vulnerability.

5.8.4 Physical vulnerability

Figure 5.13 depicts the average scores of the factors contributing to physical vulnerability. It shows the comparative intensity of each driver, which is essential for comprehending the primary variables that contribute to physical vulnerability in the context of flash floods. The study indicates that major infrastructure concerns, including broken roads and energy outages, had the highest average score of 4.06, signifying their status as the most substantial contributor to physical vulnerability. The danger of eviction due to floods is carefully studied, with an average score of 3.99. Additional factors, like water shortages during floods and disruptions in the food supply chain, also demonstrate significant influence. Conversely, accessibility issues for the elderly or crippled and the absence of secure land tenure exhibit, indicating they are comparatively less vital but still significant factors in physical vulnerability.

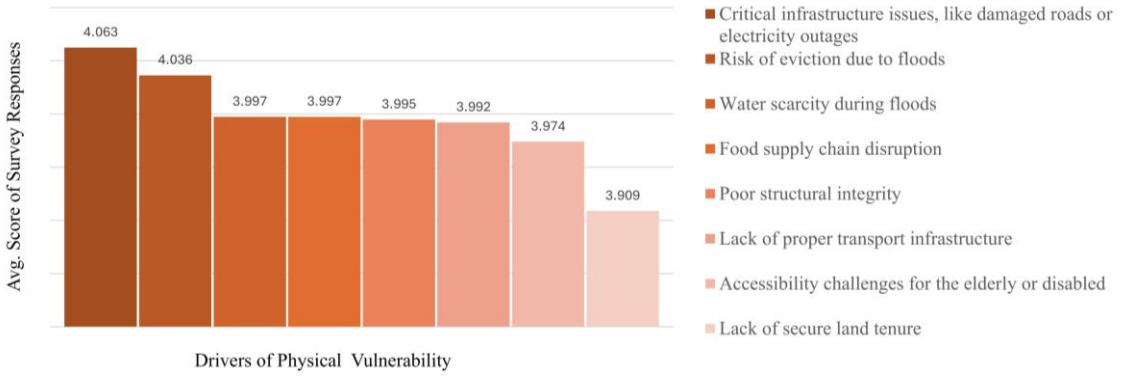


Figure 5.13. Average scores of physical vulnerability drivers.

These results underscore the pressing need to tackle major infrastructure challenges and the threat of eviction as essential concerns for mitigating physical vulnerability. This evaluation provides a solid foundation for formulating specific suggestions to alleviate the physical effects of flash floods in the area.

5.9 RELATIVE SEVERITY AMONG ALL DRIVERS

Figure 5.14 presents a comparative study of the relative severity of each driver, facilitating a thorough knowledge of their consequences and assisting in the formulation of focused recommendations. The study indicates that essential infrastructure concerns (Q23) have the highest average score, suggesting its

recognition as the most substantial factor contributing to flash flood vulnerability. This is closely followed by insufficient job possibilities (Q1, 4.05) and being in a floodplain or other high-risk zone (Q17, 4.02), all of which have significant influence. Additional significant factors are the absence of early warning systems (Q18) and the elevated expenses associated with healthcare facilities (Q10). Conversely, linguistic or cultural obstacles (Q16) and insufficient secure land tenure (Q30) exhibit the lowest average scores, indicating they are comparatively less significant but nonetheless relevant concerns.

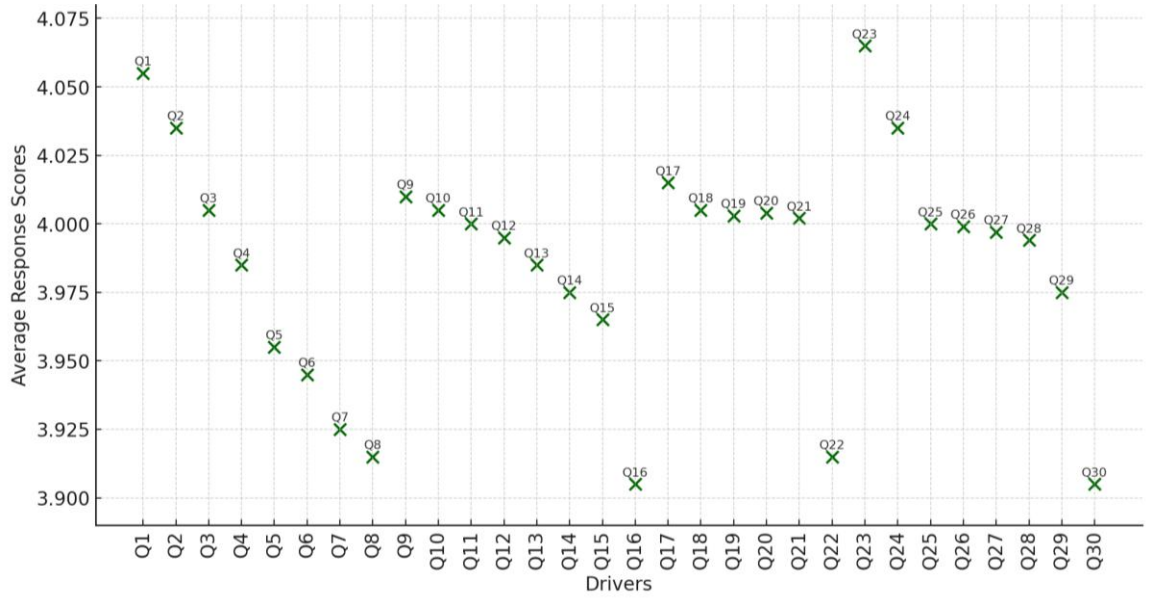


Figure 5.14. Point graph showing the average survey response distribution.

It illustrates patterns in the data, with scores typically fluctuating between 3.90 and 4.06. Factors associated with physical and economic vulnerabilities, such as Q23 (essential infrastructure difficulties) and Q1 (lack of job possibilities), typically get elevated scores, underscoring their significant contribution to worsening risk. Conversely, factors associated with social and environmental vulnerabilities, such as Q16 (language or cultural barriers) and Q22 (riverbank erosion), have marginally reduced although still significant effects. This assessment offers critical insights into the relative severity of all 30 factors, facilitating the prioritization of action areas.

5.10 CORRELATION AMONG VULNERABILITY DRIVERS

Figure 5.15 presents insights into the interrelationships among the drivers within each vulnerability dimension, helping to identify patterns and dependencies that can inform targeted interventions. The heatmap for economic vulnerability drivers in figure 5.15(a) shows strong correlations among the drivers, with values ranging from 0.76 to 0.86. The highest correlation is observed between Q2 and Q4 with a correlation coefficient of 0.86. This indicates a strong relationship between the lack of social safety nets and limited access to microcredit, both of which exacerbate economic vulnerability. Similarly, Q1 and Q2 have a correlation of 0.85, highlighting the interconnectedness of employment and social support systems.

The heatmap for social vulnerability drivers figure 5.15(b) reveals moderate to strong correlations, with values ranging from 0.83 to 0.89. The highest correlation is observed between Q10 and Q12 with a correlation coefficient of 0.89. This suggests that high healthcare costs are closely associated with corruption and bribery, which further hinder access to essential services. Additionally, Q9 and Q12 have a correlation of 0.87, indicating that corruption significantly impacts the availability of flood relief services.

The environmental vulnerability drivers in figure 5.15(c) demonstrates strong correlations, with values ranging from 0.86 to 0.90. The highest correlation is observed between Q18 and Q20 with a correlation coefficient of 0.90. This indicates that the absence of early warning systems is closely linked to the degradation of natural flood buffers, both of which increase environmental vulnerability. Similarly, Q17 and Q18 have a correlation of 0.89, emphasizing the importance of early warning systems in high-risk areas.

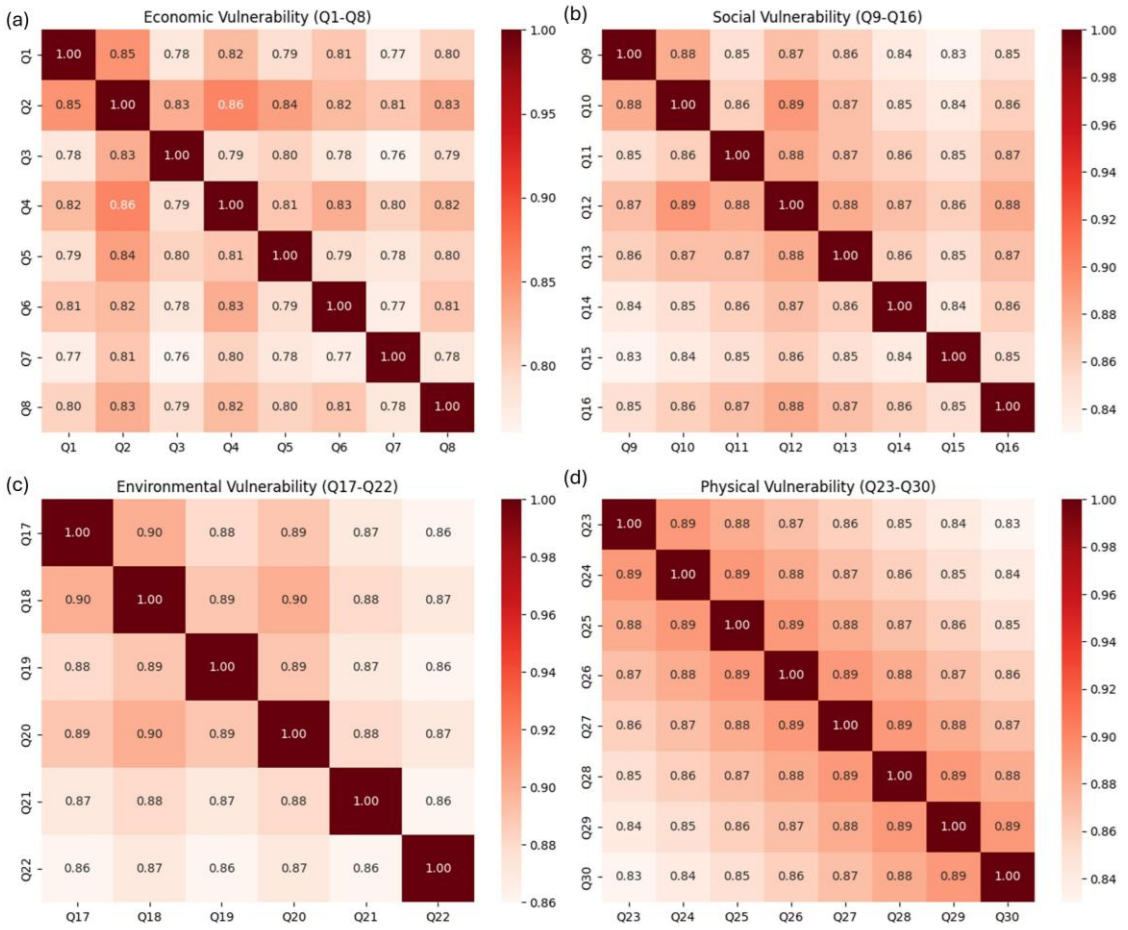


Figure 5.15. Heatmap showing correlations among (a) economic (b) social (c) environmental and (d) physical vulnerability drivers.

The physical vulnerability drivers in figure 4.15(d) shows strong correlations, with values ranging from 0.83 to 0.89. The highest correlation is observed between Q23 and Q24 with a correlation coefficient of 0.89. This suggests that infrastructure challenges are closely associated with the risk of displacement during floods. Additionally, Q25 and Q26 have a correlation of 0.89, highlighting the interconnectedness of resource scarcity and supply chain disruptions during flood events.

5.11 CORRELATION OF DRIVING FORCES AMONG VULNERABILITY DIMENSIONS

The correlation analysis among the four vulnerability dimensions (figure 5.16) reveals strong interdependencies, highlighting the interconnected nature.

All correlation coefficients exceed 0.88, indicating a high degree of association among these dimensions.

The economic dimension shows a strong correlation with the social dimension (0.92), suggesting that financial insecurity, employment status, and access to financial resources are closely linked with social factors such as community cohesion, corruption, and access to healthcare. This implies that economic instability exacerbates social vulnerability, reinforcing the need for integrated socio-economic interventions in flood-prone areas.

Similarly, the environmental dimension demonstrates strong correlations with both the social (0.91) and physical (0.92) dimensions. This relationship underscores the role of environmental degradation and inadequate flood mitigation infrastructure in shaping both social well-being and physical resilience. Communities residing in floodplains or experiencing riverbank erosion face greater risks of displacement and infrastructure failure, leading to compounding vulnerabilities.

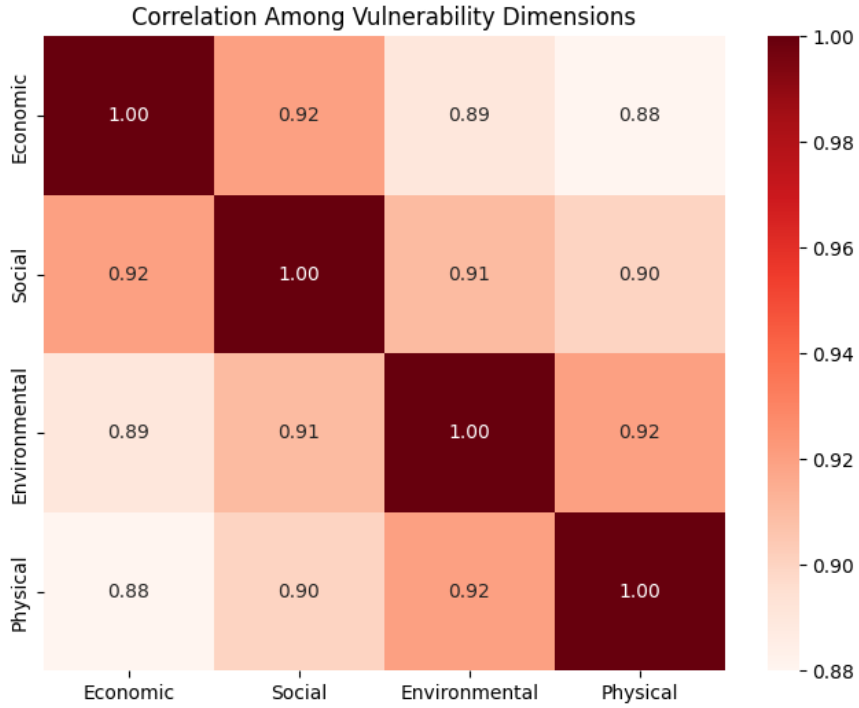


Figure 5.16: Heatmap showing correlations among the four vulnerability dimensions

The physical dimension also exhibits a significant correlation with the economic dimension (0.88), reflecting the critical influence of financial constraints on infrastructure resilience. Households with lower economic stability often lack the financial capacity to invest in flood-resistant housing and essential protective measures, thereby increasing their susceptibility to physical damage during flash flood events.

These results highlight the need for a comprehensive strategy to flood resilience, in which interventions and policies should address the linked vulnerabilities rather than focusing on individual aspects separately.

5.12 DETAILED VALIDATION FINDINGS

In this work, Receiver Operating Characteristic (ROC) curve analysis was used for the validation of flood vulnerability assessment. Indeed, this is one of the most acknowledged methods for assessing performance in spatial models and has also been widely applied in flood risk assessments [125]. The assessed vulnerability in this study was compared against the actual flood occurrences data, derived from in-person responses using a questionnaire survey. A total number of 384 random survey points (using Cochran's Formula [126]) were gathered, determined from the field within the study area. These points were overlaid with the generated overall vulnerability map, and values from the vulnerability layer extracted for every point.

The effectiveness of the vulnerability framework results for the occurrence of floods in these random places was then assessed using the ROC curve. A visual evaluation of the framework's performance is made possible by this curve, which shows the sensitivity (true positive rate) versus 1- specificity (false positive rate) for various threshold values. From the ROC curve, as represented in Figure 5.17, the AUC value of the model is 0.86 (Table 5.3), falling within the "very good" category of the standard AUC classification [125].

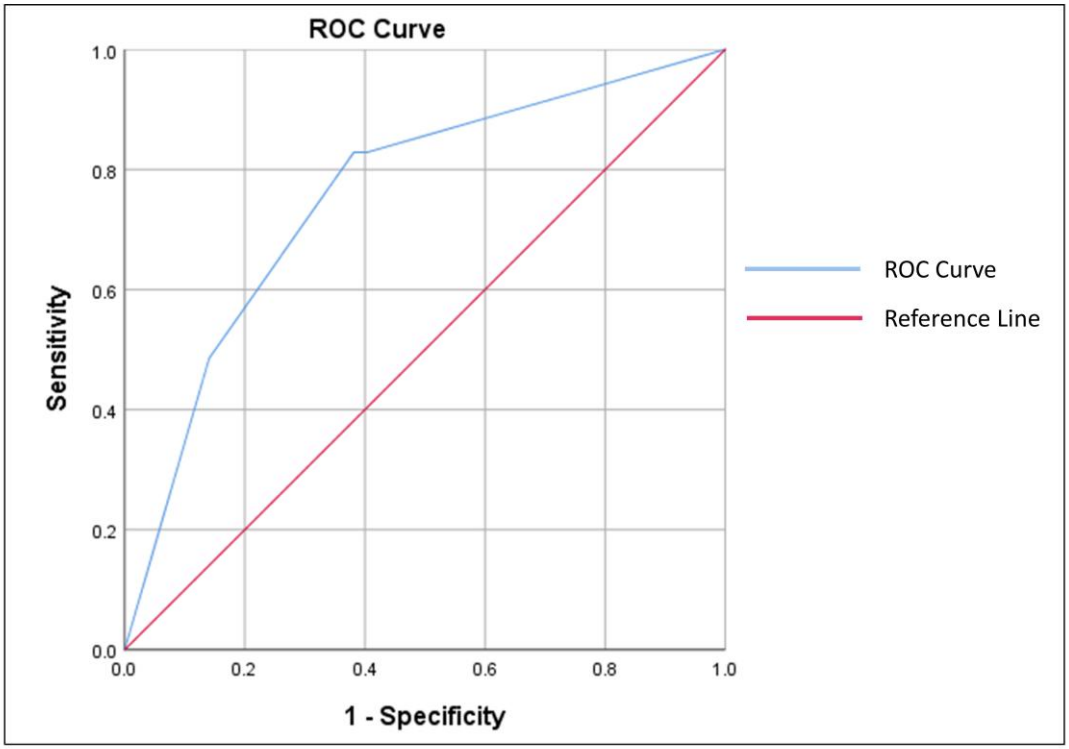


Figure 5.17. ROC curve.

The created vulnerability map, therefore, means that the overall vulnerability framework has a high assessment performance in identifying areas that are usually vulnerable to flooding. The ability to accurately assess flood-prone vulnerable areas allows local governments and disaster management organizations to identify high-risk areas and carry out focused measures to lessen the effects of upcoming floods.

Table 5.3. AUC Score.

Area Under the Curve	
Test Result Variable(s)	Scores
	0.86
Test Quality	Very Good

Chapter 6: Overview of National Policies and Frameworks for Flood Management

Flood control in Bangladesh is a crucial concern because of the nation's geographical position, hydrological features, and susceptibility to climate change [76]. The government has established many national policies and frameworks to mitigate flood hazards, which are crucial for sustainable development and catastrophe risk reduction. This study examines several pivotal national policies and frameworks for flood management in Bangladesh, including the National Water Policy (1999), National Water Management Plan (NWMP, 2001), National Disaster Management Policy (NDMP), Bangladesh Delta Plan 2100 (BDP 2100), SAARC Framework for Action (SFA), Standing Orders on Disaster 2019, Disaster Management Act, 2012 and the institutional framework for flood management in Bangladesh. This study examines the policy deficiencies and obstacles, establishing a foundation for proposals to enhance flood control techniques.

6.1 NATIONAL WATER POLICY (NWP, 1999)

The National Water Policy is fundamental to the management of water resources in Bangladesh [53]. It was designed to tackle the increasing issues of water management, including flood control, irrigation, and water delivery. The policy underscores the need for integrated water resources management (IWRM) and seeks to guarantee the sustainable utilization of water resources for economic advancement, social fairness, and environmental conservation (table 6.1). The NWP acknowledges the significance of flood management as an essential element of water resources planning and advocates for the use of both structural and non-structural strategies to alleviate flood hazards.

Nonetheless, despite its thorough methodology, the execution of the NWP has encountered several obstacles, such as inadequate coordination among

governmental bodies, insufficient financial resources, and restricted technical expertise. These issues have impeded the efficient execution of flood control initiatives, resulting in persistent susceptibility to flood hazards [53].

Table 6.1. Key Objectives of the National Water Policy (1999)

Objective	Description
Decentralization	Enhance the role of local communities and women in water management.
Public Participation	Ensure inclusive decision-making processes in water management projects.
Transboundary Cooperation	Promote bilateral and multilateral cooperation for shared water resources.
Integrated Water Resources Management (IWRM)	Ensure sustainable use of water resources for economic, social, and environmental benefits.

The NWP underscores the significance of transboundary water management, since the majority of Bangladesh's rivers come from upstream nations, including India, China, and Nepal [53]. The strategy mandates bilateral and international collaboration to oversee shared water resources and alleviate the effects of upstream operations on downstream flood hazards. The absence of collaboration has intensified flood hazards in Bangladesh, especially during the monsoon season when upstream water discharges may result in significant flooding in downstream regions.

The policy's limited focus on community-level social safety nets and livelihood security directly aligns with the high scores for lack of employment opportunities and absence of financial assistance in the economic vulnerability drivers.

6.2 NATIONAL WATER MANAGEMENT PLAN (NWMP, 2001)

The National Water Management Plan (NWMP), serves as a comprehensive framework for the management of Bangladesh's water resources. The NWMP seeks to optimize and decentralize water management, emphasizing

flood control, agriculture, and water delivery. The plan underscores the need for integrated water resources management (IWRM) and advocates for the formulation of sub-regional and local water management plans to cater to the distinct requirements of various hydrological areas [51].

A fundamental aspect of the NWMP is the identification of eight separate hydrological areas, determined by surface water flow dynamics and major river borders. The NWMP advocates for the formulation of localized flood management plans, including the erection of embankments, drainage systems, and flood shelters, alongside the execution of non-structural measures like flood forecasting and early warning systems [51].

Notwithstanding its thorough approach, the execution of the NWMP has encountered several obstacles, such as insufficient money, inadequate technical expertise, and poor coordination among governmental entities. The strategy has difficulties in incorporating climate change adaptation into flood control measures, since the effects of climate change on water resources remain inadequately comprehended [51].

The plan's heavy reliance on structural measures overlooks critical drivers such as weak infrastructure resilience and poor maintenance, which were identified as the most severe physical vulnerability factors.

6.3 NATIONAL DISASTER MANAGEMENT POLICY (NDMP)

The National Disaster Management Policy (NDMP) for 2021–2025 serves as a comprehensive framework for disaster risk mitigation in Bangladesh. The policy seeks to transition from a reactive disaster management strategy, focused on relief and recovery, to a proactive one that prioritizes risk mitigation and resilience enhancement. A primary purpose of the NDMP is to enhance the ability of local communities to manage flood hazards via its components (table 6.2). These initiatives seek to bolster the resilience of at-risk communities by

augmenting their access to information, resources, and services, while also fostering participatory decision-making processes [52].

Table 6.2. Key Components of the National Disaster Management Policy (2021–2025)

Component	Description
Community-Based Disaster Risk Reduction (CBDRR)	Enhance resilience of vulnerable communities through participatory approaches.
Early Warning Systems	Develop comprehensive flood forecasting and warning systems.
Risk Reduction	Shift from reactive relief and recovery to proactive risk reduction.
Climate Change Adaptation	Integrate climate change adaptation into disaster risk reduction strategies.

The execution of the NDMP has encountered several obstacles, such as insufficient money, inadequate technical ability, and poor cooperation among governmental institutions [52]. The strategy encounters difficulties in incorporating climate change adaptation into catastrophe risk reduction plans, since the effects of climate change on flood hazards remain little comprehended. The NDMP has been unable to adequately mitigate the increasing flood hazards in Bangladesh, especially concerning climate change and expanding urbanization [52].

The policy inadequately addresses corruption, healthcare accessibility, and community cohesion, all of which emerged as key drivers of social vulnerability in the study.

6.4 BANGLADESH DELTA PLAN 2100 (BDP 2100)

The BDP 2100 is a comprehensive strategy for sustainable water management in Bangladesh. The initiative seeks to tackle the issues of climate change, population expansion, and economic advancement via the promotion of adaptive water governance and integrated water resources management. The

BDP 2100 identifies floods as a major concern for Bangladesh and advocates for the formulation of a comprehensive flood risk management plan that incorporates both structural and non-structural solutions [55].

A fundamental element of the BDP 2100 is the establishment of a delta framework that delineates the long-term vision, scenarios, and policies for the management of water resources in Bangladesh. The proposal underscores the need for regional collaboration, to regulate shared water resources and alleviate the effects of upstream activity on downstream flood hazards. The BDP 2100 advocates for the establishment of an extensive flood forecasting and warning system, with the execution of community-oriented flood risk mitigation measures [55].

The long-term vision of the plan underemphasizes short-term drivers such as the lack of early warning systems and degradation of natural flood buffers, which were found to significantly elevate environmental vulnerability.

6.5 SAARC FRAMEWORK FOR ACTION (SFA)

The SAARC Framework for Action (SFA) serves as a regional blueprint for disaster risk mitigation in South Asia. The framework seeks to improve regional collaboration in disaster management, particularly in flood risk management, by facilitating the exchange of information, resources, and best practices. The SFA identifies floods as a major natural hazard in South Asia and advocates for the formulation of a regional flood risk management plan that include both structural and non-structural solutions [56].

Table 6.3. Key Components of the SAARC Framework for Action

Component	Description
Regional Early Warning System	Provide timely and accurate flood warnings across South Asia.
Regional Flood Risk Maps	Develop maps to identify flood-prone areas in the region.

Component	Description
Community-Based Flood Risk Reduction	Implement programs to enhance community resilience to floods.
Climate Change Adaptation	Integrate climate change adaptation into regional flood risk management strategies.

A fundamental component of the SFA is the creation of a regional early warning system for floods, designed to provide prompt and precise information to vulnerable areas across South Asia (table 6.3). The framework mandates the creation of regional flood risk maps and the execution of community-oriented flood risk mitigation plans. The execution of the SFA has encountered several obstacles, such as insufficient money, inadequate technical ability, and poor coordination among member nations. The framework encounters difficulties in incorporating climate change adaptation into flood risk management techniques, since the effects of climate change on flood hazards remain inadequately comprehended [56].

The framework's weak transboundary and regional cooperation fails to mitigate shared risks like riverbank erosion and floodplain exposure, both of which emerged as strong environmental vulnerability drivers.

6.6 STANDING ORDERS ON DISASTER 2019

By defining the roles of several government agencies and stakeholders in every stage of disaster response, the Standing Orders on Disaster (SOD) 2019 significantly influence Bangladesh's institutional approach to flood control. The SOD places a strong emphasis on community-level readiness, coordinated emergency response systems, and proactive risk reduction tactics when it comes to flood management. At the union, upazila, district, and national levels, it entails the creation of localized disaster management strategies, paying special attention to high-risk risks including urban flooding, flash floods, and riverine floods [54].

It focusses on early warning systems is one of its main characteristics. In order to guarantee that pertinent administrative and community-level actors are informed beforehand, it directs the Flood Forecasting and Warning Center (FFWC) and the Bangladesh Meteorological Department to distribute timely and accurate flood forecasts. In order to protect people and property during flood events, the directives instruct Union Disaster Management Committees (UDMCs), Upazila Disaster Management Committees (UzDMCs), and District Disaster Management Committees (DDMCs) to activate emergency shelters, evacuate populations at risk of flooding, and work with law enforcement and medical services [54].

In terms of successfully managing floods, it has significant flaws. Instead of placing as much emphasis on proactive, long-term flood risk reduction, urban flood resilience, and adaptation methods, it tends to place more emphasis on emergency response and coordination when floods occur. The SOD is devoid of comprehensive standards for incorporating climate change estimates, flash flood and urban flood-specific early warning systems, and flood zoning into local planning. Furthermore, there is still a lack of coordination between urban planning organizations and emergency management authorities, and it is unclear who is responsible for maintaining and improving flood defense systems. Consequently, compared to reactive emergency actions, preventive and resilience-building initiatives are underrepresented.

Despite its procedural detail, the framework inadequately ensures equitable resource distribution and timely assistance, reinforcing social vulnerability drivers like corruption, bribery, and lack of accessible healthcare.

6.7 DISASTER MANAGEMENT ACT, 2012

The Disaster Management Act 2012, establishes a strong framework for disaster preparedness, mitigation, and response, particularly with regard to recurrent flood hazards provides the legislative foundation for flood risk

governance in Bangladesh. The Act places flood management within the larger framework of disaster risk reduction by requiring the establishment of institutional capabilities, coordination systems, and legal responsibility to effectively address flood-related calamities [50].

It also has a number of issues with managing floods. Risk mitigation, long-term flood resilience, and climate change adaptation receive little emphasis in the Act, which primarily stresses emergency response procedures and institutional architecture. It doesn't explicitly address how to incorporate land use control measures, urban drainage planning, and flood risk mapping into disaster management plans. Furthermore, it neither strengthens the role of local government entities in proactive flood management nor requires adequate community-level engagement. Additionally, the Act does not adequately address the new issues of flash floods, urban flooding, and river erosion, which creates a disconnect between the goals of the legislation and effective, regional flood risk management measures. [50].

The act's insufficient emphasis on financial inclusion and recovery support mechanisms aligns with the identified drivers of economic vulnerability, such as exclusion from microcredit and lack of affordable insurance coverage.

6.8 INSTITUTIONAL FRAMEWORK FOR FLOOD MANAGEMENT IN BANGLADESH

The institutional architecture for flood control in Bangladesh comprises many government entities, including the Ministry of Water Resources, the Bangladesh Water Development Board (BWDB), and the Disaster Control Bureau. These agencies oversee several facets of flood management, including flood control, disaster response, and early warning systems (table 6.4).

Table 6.4: Key Institutions Involved in Flood Management in Bangladesh

Institution	Concern Ministry	Responsibilities
Water Resources Planning Organization (WARPO)	MoWR	Macroplanning of water resources management
Bangladesh Water Development Board (BWDB)	MoWR	Feasibility studies, Implementation, Operation and Maintenance (O & M) of flood management projects, Real time data collection for flood forecasting and warning services, Dissemination of flood information at national and regional levels.
Joint Rivers Commission (JRC), Bangladesh	MoWR	To conduct negotiation for data and information exchange on Trans-boundary rivers.
Bangladesh Meteorological Department (BMD)	MoD	Long, medium and short-range weather forecasting and dissemination.
Local Government Engineering Department	MLGRDC	Implementation of small scale FCDI projects.
Disaster Management Bureau (DMB)	MoDMR	Dissemination of all information on natural disaster including flood information at the community level, flood preparedness, awareness building etc.
Directorate of Relief	MoDMR	Conducting relief and rehabilitation operation in flooded areas
Local Government Institutions (LGI)	MLGRDC	Implementation and O & M of small-scale flood management project, Flood information dissemination, Relief and rehabilitation of flood victims.
Non-Government Organizations (NGO)	---	Advocacy for flood management, Relief and rehabilitation of flood victims

Institution	Concern Ministry	Responsibilities

***MoWR- Ministry of Water Resources, MoD- Ministry of Defense, MLGRDC- Ministry of Local Government Rural Development and Cooperative, MoDMR- Ministry of Disaster Management and Relief

Bangladesh's flood management institutional framework has a number of serious shortcomings that reduce its efficacy. A primary problem within the institutional structure is the delineation of policy, planning, and regulatory activities from implementation and operational functions. Despite the involvement of several agencies, including BWDB, DDM, LGED, and WARPO, their functions frequently overlap, resulting in a lack of coordination, dispersed duties, and bureaucratic hold-ups. The absence of a centralized body devoted to all-encompassing flood control causes gaps between non-structural (such as community awareness and land use planning) and structural (such as drainage systems and embankments) measures. Furthermore, programs for disaster risk reduction, climate change adaptation, and urban planning still do not adequately incorporate flood control. Effective, timely, and sustainable flood control is further hampered nationwide by a lack of finance, limited ability at the local government level, and poor use of contemporary technologies like real-time flood forecasts.

6.9 POLICY GAPS AND CHALLENGES

Despite substantial advancements in formulating flood control policies and frameworks, Bangladesh continues to face several gaps and obstacles. Addressing these deficiencies and obstacles need a more cohesive and coordinated strategy for flood control, emphasizing climate change adaptation, public engagement, and regional collaboration. By tackling these difficulties, Bangladesh can bolster its resistance to flood threats and attain sustainable development amidst escalating environmental and socio-economic obstacles.

6.9.1 Lack of Integration of Climate Change Adaptation

The National Water Policy (1999), National Water Management Plan (NWMP, 2001), and Bangladesh Delta Plan 2100 (BDP 2100) recognize the significance of climate change but lack concrete, implementable plans for incorporating climate change adaptation into flood control [51], [53], [55]. In the absence of climate-resilient flood control techniques, Bangladesh is significantly susceptible to future flood hazards intensified by climate change.

6.9.2 Insufficient Focus on Non-Structural Measures

Existing policies, including the NWP and NWMP, predominantly focus on structural interventions (e.g., embankments, drainage systems) while inadequately employing non-structural strategies such as flood forecasting, early warning systems, community-based disaster risk reduction (CBDRR), and flood insurance [51], [53]. Structural solutions alone are inadequate to mitigate the intricate and evolving nature of flood threats, particularly in high-vulnerability regions. Non-structural strategies are essential for bolstering community resilience and mitigating socio-economic effects.

6.9.3 Limited Public Participation and Community Engagement

The NWP underscores the need of public engagement, but its execution has been constrained [21]. Local communities, particularly in high-vulnerability unions, are often marginalized in decision-making procedures concerning flood control [53]. In the absence of community engagement, flood control techniques may fail to meet the distinct demands and vulnerabilities of local people.

6.9.4 Inadequate Coordination Among Institutions

The institutional architecture for flood control in Bangladesh comprises many institutions (e.g., Ministry of Water Resources, BWDB, DMB); nevertheless, coordination among these entities is often inadequate. This results in disjointed and ineffective flood control initiatives [104]. Inadequate coordination obstructs

the execution of integrated flood risk management measures, especially in high-vulnerability regions where simultaneous actions are essential.

6.9.5 Lack of Regional and Transboundary Cooperation

The majority of Bangladesh's rivers come from upstream nations, such as India and Nepal; nevertheless, there is little collaboration on transboundary water management and flood risk mitigation [103]. The SAARC Framework for Action (SFA) establishes a foundation for regional collaboration; nonetheless, progress has been sluggish [105]. Upstream operations, including dam building and water discharge, intensify downstream floods in Bangladesh, especially in high-risk regions next to transboundary rivers.

6.9.6 Insufficient Funding and Technical Capacity

Flood control initiatives in Bangladesh often encounter financial deficits and insufficient technical proficiency, especially at the local tier [74]. This constrains the execution of both structural and non-structural interventions. High-vulnerability regions, often lack the resources and technical expertise necessary to execute successful flood risk mitigation strategies [106].

6.9.7 Inadequate Priority Focus on High-Vulnerability Areas

Existing policies and frameworks inadequately priorities regions of high risk. These regions often have distinct issues (e.g., inadequate infrastructure, elevated population density) that need specific approaches [107]. In the absence of focused actions, high-vulnerability unions would persist in suffering the most from flood effects, resulting in heightened socio-economic losses and relocation.

6.10 COMPARATIVE ASSESSMENT AMONG POLICY PRACTICES

Bangladesh has developed a diverse set of policies to address water-related hazards, including flash floods, each emphasizing different dimensions of vulnerability and resilience. The National Water Policy (1999) and National Water Management Plan (2001) focus primarily on integrated water resources

management, emphasizing flood control, drainage, irrigation, and sustainable water use to reduce exposure to flood risks. In contrast, the National Disaster Management Policy (NDMP) and the Disaster Management Act (2012) provide a more comprehensive disaster risk reduction (DRR) framework, shifting from a relief-centric to a preparedness and resilience-based approach, where flash floods are recognized as recurring hazards requiring community-based responses, institutional capacity building, and risk governance mechanisms. Similarly, the Standing Orders on Disaster (2019) operationalize disaster management at national to local levels, outlining responsibilities of government agencies to ensure coordinated early warning, evacuation, and emergency response.

Long-term strategic frameworks such as the Bangladesh Delta Plan 2100 (BDP 2100) adopt a forward-looking approach, integrating climate change adaptation, river basin management, and land use planning to enhance resilience against increasing flash flood threats. At the regional scale, the SAARC Framework for Action (SFA) complements national efforts by fostering cross-border cooperation, particularly relevant for flash floods driven by upstream rainfall and transboundary river flows. Taken together, these policies collectively aim to reduce flash flood vulnerability through structural measures (embankments, water regulation), non-structural measures (early warning, institutional capacity, community engagement), and long-term adaptation planning. However, gaps remain in implementation and inter-agency coordination, where integration between national frameworks and transboundary cooperation is critical to effectively manage flash flood risks in Bangladesh.

6.11 RECOMMENDATIONS FOR ENHANCING FLOOD RESILIENCE THROUGH MINIMIZING DRIVING FORCES IMPACT

The findings of this study provide a comprehensive understanding of the key drivers of flash flood vulnerability in the Feni district. Based on the survey

data, economic, social, environmental, and physical vulnerabilities were assessed to identify the most impactful drivers. The analysis also revealed strong interdependencies among different vulnerability dimensions. Furthermore, policy evaluation highlighted critical gaps in the existing flood management framework.

6.11.1 Framework for Minimizing Multidimensional Flash Flood Vulnerability Drivers

Economic vulnerability, as indicated by high response scores, is one of the primary concerns. Households facing financial insecurity are less capable of coping with flood disasters. To enhance economic resilience, targeted interventions has been designed in table 6.5. Whereas social factors such as corruption in aid distribution (Q24: 4.03) and inadequate healthcare services (Q17: 4.02) exacerbate vulnerability. To build social preparedness, community-based disaster risk reduction strategies has been strengthened (Table 6.5).

Table 6.5. Proposed Recommendation Framework for Minimizing Drivers of Flash Flood Vulnerability

Key Dimensions	Key Drivers (Mean Score)	Proposed Solutions	Supporting References	Implementation Strategy	Expected Outcomes
Economic Vulnerability	Lack of employment (4.05), no social safety nets (4.04), inadequate savings (4.00)	Launch flood-resilient employment programs and expand social protection schemes	[108], [109]	Establish government-supported income diversification initiatives (e.g., flood-tolerant agriculture, small businesses), increase budget allocation for social safety nets	Improved income security; reduced post-flood economic shock
	Lack of microcredit (3.98), insurance (3.96), high mitigation cost (3.94)	Provide subsidized microcredit and affordable insurance for at-risk households	[110]	Partner with NGOs, MFIs, and private insurers to introduce low-interest loans and community-based insurance schemes	Enhanced household preparedness; greater financial risk-sharing
	Wage theft (3.93), lack of financial aid (3.92)	Strengthen Labor rights and introduce emergency financial aid systems	[111], [112]	Enforce local Labor regulations; create a disaster-response emergency relief fund accessible through local administration	Reduced exploitation and faster financial recovery after flood events

Social Vulnerability	Poor access to relief (4.01), healthcare costs (4.01), corruption (4.00)	Develop transparent, community-based relief and health service delivery mechanisms	[113]	Digitize aid distribution, implement mobile healthcare units, establish anti-corruption monitoring boards	Equitable access to relief and health services
	Bribery (3.99), lack of healthcare (3.99), poor sanitation (3.97)	Upgrade local healthcare and WASH (Water, Sanitation, and Hygiene) infrastructure	[101]	Build/renovate local clinics and flood-resilient sanitation blocks, ensure affordable service access	Improved public health during and after floods
	Weak social networks (3.91), cultural barriers (3.91)	Strengthen local disaster response networks and multilingual communication tools	[57], [93]	Form community-based disaster management committees (CDMCs), distribute culturally inclusive flood info materials	Increased community participation and inclusive flood response
Environmental Vulnerability	Settlement in floodplains (4.02), lack of early warning (4.01)	Update land zoning laws, install modern and real-time flood early warning systems	[46]	Integrate geospatial data into planning laws, expand FFWC sensor network and develop mobile alert apps	Reduced exposure, timely evacuation and response

	Low-lying terrain (4.01), degraded buffers (3.93), riverbank erosion (3.93)	Promote nature-based solutions like wetland restoration and riverbank stabilization	[114]	Launch reforestation drives, embankment strengthening, and community wetland co-management programs	Recovered natural buffers, reduced erosion, lower floodwater velocity
Physical Vulnerability	Infrastructure damage (4.06), eviction risk (4.04), water scarcity (3.99)	Improve infrastructure with flood-resilient design and protect land tenure rights	[57], [93], [112]	Reconstruct roads, utilities, and flood shelters to resilient standards, issue legal land tenure documents in vulnerable settlements	Increased physical protection, reduced displacement risk
	Food supply issues (3.99), poor housing (3.99), transport gaps (3.99)	Strengthen flood-proof food storage, housing, and transport corridors	[88]	Build raised storage depots and shelters, maintain all-season access roads and install culverts in vulnerable routes	Ensured food security and mobility during floods
	Elderly/disabled access (3.97), insecure land tenure (3.91)	Introduce inclusive shelter design and legal aid for tenure regularization	[115]	Create accessible shelter ramps, separate elderly units, partner with legal NGOs to assist with land tenure formalization	Enhanced safety for vulnerable groups, reduction in tenure-related eviction post-flood

Moreover, environmental and physical drivers play a crucial role in increasing flood vulnerability.

6.11.2 Recommendation Framework for Minimizing Policy Gaps

The evaluation of existing policies identified several gaps in flood management strategies. Although Bangladesh has a comprehensive water management framework, its implementation at the local level remains weak. The following steps are necessary to bridge these policy gaps in table 6.6.

Table 6.6. Proposed Recommendation Framework for Minimizing Existing Policy Gaps

Key Issues	Proposed Solutions	Supporting References	Implementation Strategy
Policy Integration and Institutional Strengthening	Decentralization of Flood Governance.	[116]	Decision-making power should be delegated to district and union-level authorities to ensure localized responses. A dedicated flood risk management unit should be established at the district level to coordinate efforts across various sectors.
	Integration of flash flood mitigation into national policies.	[117]	The Bangladesh Delta Plan 2100 and National Water Policy should incorporate specific provisions for flash flood-prone regions such as Feni. A dedicated action plan should be formulated to ensure targeted investments in flood resilience.
	Cross-sectoral collaboration.	[111]	Flood management requires an integrated approach involving multiple stakeholders, including the Water Development Board, Department of Disaster Management, and NGOs. A cross-sectoral coordination framework should be developed to facilitate information sharing and joint implementation of resilience measures.

	Revision of national water policy and flood management plans.	[118]	The existing National Water Policy (NWP) and National Water Management Plan (NWMP) need to be revised to incorporate specific provisions for flash flood management. The policy should emphasize the integration of both structural and non-structural measures. A separate Flash Flood Management Policy should be developed, focusing on the unique hydrological and geographical characteristics. This policy should include provisions for flood risk mapping, early warning systems, and community-based flood preparedness programs.
	Climate change integration in policy frameworks	[119]	Climate change is a significant driver of flash flood vulnerability, as evidenced by the increasing frequency and intensity of extreme rainfall events. The revised policies should incorporate climate change adaptation strategies, including the development of climate-resilient infrastructure and the promotion of climate-smart agricultural practices. The National Adaptation Plan (NAP) should be updated to include specific measures for flash flood-prone areas like Feni.
	Strengthening community-based	[120]	Community engagement is crucial for effective flood risk management. The government, in collaboration with NGOs and local authorities, should

Community Engagement and Capacity Building	flood preparedness		establish Community-Based Flood Preparedness Programs (CBFPPs). These programs should focus on raising awareness about flood risks, training community members in emergency response, and promoting the use of flood insurance as a risk mitigation tool. The programs should promote social cohesion and community networks to enhance collective action during flood events.
	Enhancing public participation in decision-making	[118]	Public participation in flood management planning and decision-making processes should be institutionalized. This can be achieved through the establishment of Local Flood Management Committees (LFMCs) at the upazila and union levels. These committees should include representatives from affected communities, local government officials, and water management experts.
	Education and training programs	[87], [121]	Educational programs targeting vulnerable communities should be implemented to enhance their understanding of flood risks and mitigation measures. These programs should include workshops, training sessions, and the dissemination of educational materials in local languages. Additionally, school-based flood education programs should be introduced

			to ensure that the younger generation is well-informed about flood risks and preparedness. Training programs should include modules on emergency evacuation procedures and accessibility challenges for the elderly or disabled.
Infrastructure Development and Maintenance	Improvement of structural flood control measures	[122]	The existing structural measures, such as embankments, sluices, and drainage channels, need to be upgraded and maintained regularly. The flood control, drainage, and irrigation projects should be revisited to address its shortcomings, particularly the ineffective positioning of the rubber dam. New dykes and sluices should be constructed based on hydrological modelling and community feedback to ensure their effectiveness.
	Development of flash flood forecasting and early warning systems	[122]	An advanced Flash Flood Forecasting and Early Warning System (FFFEWS) should be developed. This system should integrate real-time hydrological data, weather forecasts, and community feedback to provide accurate and timely flood warnings. The system should be accessible to all stakeholders, including local authorities, community members, and NGOs.

	Promotion of nature-based solutions	[91]	Nature-based solutions, such as wetland restoration, afforestation, and the construction of green infrastructure, should be promoted to enhance the natural capacity of the landscape to absorb and retain floodwaters. Nature-based solutions should be prioritized to address degradation of natural flood buffers and riverbank erosion.
Financial Mechanisms and Resource Allocation	Establishment of a flood risk management fund	[123]	A dedicated Flood Risk Management Fund (FRMF) should be established to finance flood control projects, community preparedness programs, and research initiatives. The fund should be supported by both government allocations and international donor agencies.
	Promotion of Public-Private Partnerships	[124]	Public-private partnerships (PPPs) should be encouraged to mobilize additional resources for flood risk management. Private sector involvement can be particularly beneficial in the development of early warning systems, flood insurance schemes, and infrastructure projects. PPPs should focus on providing affordable insurance coverage and microcredit opportunities to flood-affected communities.

Chapter 7: Discussion

This chapter analyses the study's important findings by evaluating the results of the multidimensional flash flood vulnerability assessment, focusing on regional patterns and severity across social, physical, economic, and environmental aspects. It also examines the factors that contribute to these vulnerabilities and how they are interrelated, providing information on the environmental and socioeconomic stresses that increase the risk of flooding. The chapter considers the implications of current policy frameworks for local resilience while assessing their efficacy and weaknesses. The findings' potential uses by planners, legislators, and disaster management authorities are examined. The chapter concludes by acknowledging the limits of the study and offering suggestions for future research that will advance resilience methods and vulnerability assessments.

7.1 INSIGHTS FROM THE MULTIDIMENSIONAL VULNERABILITY ASSESSMENT

The spatial pattern of vulnerability in Feni District reflects high geographic variability within the district and is produced by the combined processes of social, economic, physical, and environmental factors. This supports the idea that vulnerability is context-specific and multi-scalar, which is more widely accepted in the literature on disaster risk. Prior studies [127], [128] emphasize that vulnerability is the outcome of the dynamic interaction of different exposure, susceptibility, and resilience components. This is reflected in the vulnerability pattern, which shows that, across the district, vulnerability to flash floods is not uniform. Higher vulnerability occurs in certain areas where a set of dimensions combine, resulting in a higher level of vulnerability to flash flooding. The study found that the southern and central parts of the district are the most vulnerable, especially Feni Sadar and Sonagazi unions, which fall within high social

vulnerability driven by population density and age-related factors, and also within highly economically vulnerable conditions resulting from rapid urbanization and unemployment. In addition, these regions are poorly settled physically because the elevation is low, and drainage systems are not well designed to reduce flood occurrences. This result is in line global studies like those of [28], [36], which highlight that socioeconomic pressures and inadequate physical infrastructure create vulnerability hotspots, which are more likely to experience the effects of disasters.

The results of composite vulnerability analysis showed that nearly 30% of the district falls within a very low vulnerability class, mainly in the north, where higher elevation combined with better drainage systems and relatively low population densities brings the flood risk down. This is in line with the findings of [31], [40], who highlighted the importance of infrastructure quality and natural topography in determining flood risk and mitigating potential.

On the other hand, about 12% of the district falls into a very high vulnerability category, indicating areas where all the social, economic, physical, and environmental factors coincide to raise flood susceptibility. Studies like [29] have noted this tendency and contend that multidimensional vulnerability frameworks provide a more accurate depiction of areas that are at risk, particularly in areas that are prone to flooding. These findings imply that the flood vulnerability of the Feni District is due to a complex interplay of natural and human-induced factors, with different regions more likely than others to incur flood risks associated with physical environmental and socio-economic attributes.

Policy and practice, especially with regard to flood vulnerability management in Feni District, will benefit greatly from the results of this study.

7.2 UNDERSTANDING THE ROLE OF DRIVERS IN SHAPING FLASH FLOOD VULNERABILITY

This study examines the flash flood vulnerability by delving into the underlying drivers across multiple dimensions and evaluating existing flood management policies. The ultimate target was to generate actionable, evidence-based recommendations to enhance flood resilience and adaptive capacity in a region where flash floods pose recurrent and significant threats by examining the multi-dimensional drivers that contribute to the region's heightened flood vulnerability. The study, surveyed 384 respondents with average scores ranging from 3.91 to 4.06 on a 5-point scale, revealed a pervasive sense of vulnerability across all dimensions. The empirical evidence, derived from both detailed survey data and spatial analysis, underscores not only the widespread vulnerability but also the multifaceted nature of the underlying challenges. By integrating quantitative findings with an evaluation of national flood management policies, the study has generated actionable recommendations that are poised to transform flash flood resilience strategies in a region where flash floods represent a recurrent and significant threat.

The key findings reflect a critical interplay among various vulnerability drivers. Economically, the high average responses highlight severe constraints such as limited employment opportunities, inadequate access to financial services including microcredit and insurance, and the absence of comprehensive social safety nets. Socially, the study points to significant challenges in accessing essential flood relief services, healthcare, and reliable sanitation facilities, compounded by pervasive corruption and declining community cohesion. Environmentally, the loss of natural flood buffers due to deforestation and riverbank erosion, alongside the inadequacy of early warning systems, has been shown to substantially exacerbate flood risk. Physically, the evidence indicates that deteriorating infrastructure, ranging from poorly maintained roads and unreliable power supplies to substandard housing and an increased risk of

eviction, further deepens the district's vulnerability. This confluence of factors creates a compounded risk that not only threatens immediate lives and property but also undermines long-term regional development and socioeconomic stability [76].

This study not only confirms previous studies that have identified economic hardship, inadequate social infrastructures, and environmental degradation as central components of flood vulnerability in Bangladesh [6], [22], [129], [130], but also extends the current understanding by demonstrating, through empirical correlation analyses, the complex interlinkages among these factors. The study illuminates how limited access to microcredit and financial safety nets not only exacerbates economic vulnerability but also amplifies the impact of physical infrastructure deficiencies on community recovery. In doing so, it builds on the established theoretical foundations such as the DPSIR (Driver-Pressure-State-Impact-Response) framework [46], reinforcing the notion that vulnerability is not the result of isolated factors but rather the product of a dynamic interplay among multiple domains. This holistic perspective necessitates that any effective flood management strategy in Feni District or similarly affected regions, must be integrative and multidisciplinary in nature, transcending the limitations of traditional approaches.

7.3 CRITICAL REFLECTIONS ON POLICY FRAMEWORKS FOR FLOOD MANAGEMENT

The policy dimension of the study's findings also offers particularly compelling outcome. The analysis reveals that existing flood management policies fall short in terms of practical, on-the-ground implementation, especially in the context of integrated, community-based disaster management [50], [51], [52], [53], [55], [131]. The study founds those deficiencies in early warning systems, fragmented institutional responsibilities, and a lack of coordinated action significantly hamper effective flood response. Addressing these policy

gaps is not a matter of administrative alteration, it is an imperative for fundamental reform that can redefine flood management practices across the region.

The significance of these findings lies in their ability to address a long-standing gap in flood risk management literature and practice. By systematically quantifying and analysing the severity and interdependencies of vulnerability factors, the study provides a strong framework that bridges academic inquiry with practical interventions. The high levels of economic and social vulnerability, reinforce the idea that even minor economic shocks can have profound ripple effects throughout communities already under significant stress.

7.4 IMPLICATIONS FOR PRACTICE AND COMMUNITY RESILIENCE

The practical implications of this study are multifaceted. On an economic level, the study clearly indicates that interventions aimed at enhancing flood-resilient employment opportunities and improving access to financial services could have a transformative impact on community resilience. Environmental management emerges as a critical area where immediate action is required [74]. The study's highlights the urgent need for reforestation programs, wetland restoration, and the installation of advanced early warning systems. Strengthening these natural defences can reduce surface runoff and mitigate the severe impacts of flash floods. In parallel, the physical vulnerability findings point to the necessity of upgrading critical infrastructure. Investments in flood-resistant housing, elevated transportation networks, and robust utility systems are not merely capital expenditures, they are strategic initiatives that safeguard the long-term economic and social wellbeing of the district [101].

7.5 LIMITATIONS

Although the present study provides valuable insights into flood vulnerability, it is important to acknowledge several limitations. One major

constraint lies in the availability and resolution of data. Reliance on secondary data sources, such as demographic information and land-use datasets at 30-m resolution, limits the ability to capture micro-level variations, particularly in rapidly urbanizing areas where conditions change quickly. Another limitation stems from the methodological reliance on Principal Component Analysis (PCA). While PCA is a robust tool for objectively assigning weights to indicators and reducing dimensionality, it prioritizes statistical variance, which may not fully capture the complex and often nonlinear causal relationships among vulnerability indicators. This is particularly relevant for social and environmental components, where contextual and qualitative nuances play a critical role. In addition, the study did not incorporate Key Informant Interviews (KII), which could have provided deeper qualitative insights and validation of the identified drivers of vulnerability. The absence of KIIs restricts the integration of expert and local perspectives, thereby narrowing the interpretive depth of the findings.

7.6 DIRECTION FOR FUTURE STUDY

Future research should use other techniques to supplement PCA results in order to lessen these problems. It is possible to confirm the vulnerability assessments and offer crucial context by including stakeholder viewpoints and expert opinion using field data gathering techniques, like questionnaires and interviews. By shedding light on the impact of individual variables outside of their statistical correlations, sensitivity analysis may further improve the robustness of the model. When combined, these strategies will make sure that the weighing process represents the intrinsic complexity of vulnerability dynamics and captures empirical linkages, resulting in a more thorough and contextually appropriate evaluation.

In synthesizing the study's contributions, it is clear that the integrated approach adopted in this research represents a significant advancement in flood

risk management. The rigorous methodological framework, combining quantitative survey data, sophisticated spatial analysis, and comprehensive policy evaluation, has yielded a multidimensional portrait of flood vulnerability that is both detailed and actionable. These findings collectively underscore that addressing flash flood vulnerability requires a holistic approach that is both integrative and transformative. The implications of this study extend beyond the Feni District, offering valuable lessons for flood management in similar contexts around the world.

Chapter 8: CONCLUSIONS

The main conclusions of the flash flood vulnerability assessment in Feni District are summarized in this chapter, which also highlights the regional differences and intensity of vulnerabilities across social, physical, economic, and environmental aspects. It highlights how many factors shape these vulnerabilities and points out important governance and policy shortcomings that prevent effective flood resilience. The chapter considers the goals of the study and how integrated geospatial and mixed-method approaches were used to achieve them. Lastly, it outlines the study's wider significance for future flood risk management and policy development in Bangladesh and offers practical suggestions for lowering vulnerability and boosting resilience.

8.1 GENERAL

The present study is an overall assessment of flood vulnerability in the district of Feni by using an integrated geospatial approach, i.e. the integration of different factors that show multi-dimensional pathways through which different dimensions of vulnerability intersect with each other to create a diverse spatial pattern of vulnerability to floods.

Results show that flash flood vulnerability varied over space in Feni District, indicating a larger area of the southern and central parts, and most of Feni Sadar and Sonagazi, falling into a high vulnerability zone. These areas were characterized by high population density, rapid urbanization, and inadequate drainage infrastructure, hence their high susceptibility to flood impacts. In contrast, areas in the northern parts of this district, such as Parshuram and Anandapur, present much lower vulnerability relatively, due to favorable physical conditions along with a low order of social and economic pressures.

Some of the contributions that arise from this study involve using a multi-dimensional framework to conduct flood vulnerability assessment; therefore, it

could provide a more holistic understanding of the various contributing factors associated with flash flood vulnerability. The results show that social vulnerability plays a leading role in shaping overall vulnerability in Feni District. This is followed by economic vulnerability, which perpetuates flood risks in urban areas. In addition, physical factors, such as elevation and drainage density, were also considerable variables that determined the degree of flood exposure, particularly in low-lying areas with inefficient infrastructure. At the same time, environmental vulnerability, which is conditioned by rainfall intensity and growth of urban agglomerations, was especially high in the southern parts of the district due to rapid urban development, resulting in a great increase in impervious surfaces and low resilience against flooding. The ROC curve analysis for the model validation showed that the reliability of the model was confirmed. An AUC score of 0.86 gave proof that the framework was highly effective in assessing flood-prone areas. The capability of identifying vulnerable areas with high accuracy based on multi-dimensional integration provides a strong tool for local authorities and disaster management agencies looking to enhance resilience against flood hazards.

These findings have many consequences for flood preparedness and mitigation strategies in the Feni District. Appropriate measures aimed at flood risk reduction, e.g., improving drainage systems as well as construction of flood resilient structures and provision of flood shelters, should be carried out more urgently in areas that have been marked as high risk, such as Feni Sadar and Sonagazi. The study has also indicated that most of the flood prone communities should be targeted for socio-economic initiatives that, for instance, aim at enhancing better health care services and creating jobs as a way of helping the communities deal with the effects of the floods.

As a result, this study provides a solid framework for evaluating the Feni District's flood vulnerability and practical insights for improving flood risk management in the area. The research offers a comprehensive study of flood risk

by combining social, economic, physical, and environmental aspects. It also identifies the regions and characteristics that have the greatest impact on susceptibility. The results emphasize the necessity of a multifaceted strategy for flood preparedness, integrating environmental, socioeconomic, and infrastructure enhancements to lessen the district's total flood susceptibility.

8.2 KEY FINDINGS

Here are the major findings from coastal erosion vulnerability in the Chattogram district:

1. **Social Vulnerability Disparities:** Unions such as Mirzanagar (87.5%), Sindurpur (73.2%), Purba Chandrapur (72.9%), Rajapur (71.1%), and Darbarpur (70.2%) exhibit very low social vulnerability, whereas Nawabpur (41.7% high; 42.6% very high) and Dharmapur (37.2% high) are the most socially vulnerable areas.
2. **Physical Vulnerability Patterns:** Mohamaya (55.2%), Amjadhat (54.9%), Baksh Mohammad (49.8%), and Subhapur (48.9%) have the lowest physical vulnerability, while Yakubpur (58.6% moderate/high) and Char Chandia (51.9% moderate/high; 15.6% very high) face the greatest infrastructure-related risks.
3. **Economic Vulnerability Variations:** Baligaon (78.7%), Kazirbag (74.8%), and Kalidah (72.0%) show very low economic vulnerability, in contrast to Amjadhat (80.6% high) and Mohamaya (76.2% high). Char Chandia stands out with 33.1% of its area at very high economic risk.
4. **Environmental Vulnerability Patterns:** Dhalia (86.9%), Purba Chandrapur (86.5%), and Rajapur (84.6%) are the least environmentally vulnerable unions, whereas Mohamaya (99.3%), Amjadhat (79.0%), and Feni Paurashava (68.9%) are almost entirely in the very high vulnerability category.

5. **Composite Vulnerability Distribution:** Approximately 30 % of Feni District falls under very low overall vulnerability, 22% low, 18% moderate, 17% high, and 13% very high, reflecting cumulative spatial patterns across all four dimensions.
6. **Inter-Dimensional Correlations:** Overall vulnerability correlates strongly with social (r=0.79), economic (r=0.75), and environmental (r=0.76) dimensions, and moderately with physical vulnerability (r=0.52), indicating the pre-eminence of socio-economic and ecological factors.
7. **Cross-Dimension Linkages:** Economic and environmental vulnerabilities exhibit a very strong mutual correlation (r=0.88), while economic shows moderate associations with physical (r=0.66) and social (r=0.55) dimensions. Physical vulnerability correlates moderately with environmental (r=0.56) and less so with social (r=0.50).
8. **Overall Vulnerability Dimension Assessment:**
    - Economic vulnerability received the highest average score (4.3), making it the most critical concern in the study area.
    - Social vulnerability followed with an average score of 4.0, then environmental (3.8) and physical vulnerability (3.5).
    - The economic dimension had the highest median, reflecting widespread concern, but all dimensions displayed substantial variability.
9. **Economic Vulnerability Drivers:**
    - Lack of employment opportunities is the most significant economic driver (avg. score 4.75).
    - Lack of social safety nets (4.50) and high cost of mitigation measures (4.25) also contribute strongly.
    - Absence of government financial aid (4.00) is another major concern.

- Wage theft (3.75) and insufficient savings (3.50) were relatively less impactful but still relevant.

10. Social Vulnerability Drivers:

- High healthcare costs and lack of accessible health centers are the top drivers (avg. score 4.01).
- Poor sanitary facilities and weak social cohesion follow closely (avg. score 3.99).
- Linguistic/cultural barriers (3.95) and corruption/bribery (3.94) are slightly lower but still notable.

11. Environmental Vulnerability Drivers:

- Residing in flood-prone/high-risk areas (avg. score 4.02) is the most impactful driver.
- Lack of early warning systems and loss of natural buffers scored 4.01, indicating critical issues.
- Riverbank erosion (4.0), deforestation (3.98), and pollution (3.98) also contribute significantly.

12. Physical Vulnerability Drivers:

- Broken infrastructure (roads, power outages) is the leading driver (avg. score 4.06).
- Risk of flood-related eviction (3.99) and shortages of water and food are significant concerns.
- Access issues for elderly/disabled and lack of secure land tenure were relatively less impactful but still relevant.

13. Most Severe Individual Drivers (Across All Dimensions):

- Essential infrastructure problems (Q23) had the highest overall score, making it the top priority.

- Other top drivers: Lack of job opportunities (Q1 – avg. score 4.05), Living in high-risk flood zones (Q17 – avg. 4.02), Lack of early warning systems (Q18), High healthcare costs (Q10).
- Lowest scoring factors: Language/cultural barriers (Q16), Insecure land tenure (Q30).

14. Strong inter-driver correlations exist within each dimension:

- Economic: Highest between lack of social safety nets and microcredit (0.86).
- Social: Highest between healthcare costs and corruption (0.89).
- Environmental: Highest between absence of warning systems and loss of flood buffers (0.90).
- Physical: Highest between infrastructure damage and flood-related displacement (0.89).

15. All four dimensions are strongly correlated (coefficients > 0.88), revealing interconnected vulnerabilities.

- Economic and Social: Highest correlation (0.92), indicating socio-economic inseparability.
- Environmental-Physical (0.92) and Environmental-Social (0.91) are also closely linked.
- Economic-Physical (0.88): Highlights how financial constraints increase physical risk.

16. Policy Gaps and Challenges:

- Lack of Integration of Climate Change Adaptation.
- Insufficient Focus on Non-Structural Measures.
- Limited Public Participation and Community Engagement.
- Inadequate Coordination Among Institutions.
- Lack of Regional and Transboundary Cooperation.
- Insufficient Funding and Technical Capacity.

- Inadequate Priority Focus on High-Vulnerability Areas.

17. Recommendations for Enhancing Flood Resilience:

- Development framework for Minimizing Multidimensional Flash Flood Vulnerability Drivers.
- Proposed Recommendation Framework for Minimizing Existing Policy Gaps.

8.3 SUMMARY

Using both geospatial analysis and a driver-based perception survey, this study thoroughly evaluated the Feni district's vulnerability to flash floods from an economic, social, environmental, and physical perspective. According to the investigation, the most important factor was economic vulnerability. Poor sanitation, a lack of social cohesiveness, and restricted access to reasonably priced healthcare were the main causes of social vulnerability, which came in second. Living in flood-prone areas, not having early warning systems, and environmental deterioration all contributed to environmental vulnerability. The main factors affecting physical vulnerability during floods were resource shortages, displacement hazards, and infrastructural failures. Infrastructure failure, economic insecurity, and spatial exposure to risks are the most urgent issues, according to a comparative severity study. Furthermore, the interdependence of physical, environmental, and socioeconomic determinants is highlighted by substantial correlations both within and between vulnerability dimensions, underscoring the necessity of coordinated and integrated interventions. In order to address the compounded and overlapping vulnerabilities affecting at-risk communities in Feni district, the findings highlight the need for a comprehensive strategy that includes infrastructure resilience, targeted economic support, easily accessible healthcare, enhanced early warning systems, and inclusive planning.

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Appendices

Appendix A: Questionnaire of the survey

Questionnaire Survey on

Drivers of Flash Flood Vulnerability Assessment Questionnaire

MURP Thesis: Department of Urban and Regional Planning, CUET, Chattogram

(Used only for Academic Purposes)

Survey Location:	Union:	Questionnaire No:

Please rate your level of agreement with the following statements on a scale from 1 to 5, where 1 indicates "Strongly Disagree" and 5 indicates "Strongly Agree"

A. Economic Vulnerability

1. Does the lack of employment opportunities in your community affect your vulnerability to floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

2. Do instances of wage theft impact your economic stability, making you more vulnerable during flood situations?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

3. Does the absence of social safety net services leave your community more exposed to economic hardships during and after floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

4. Are you excluded from microcredit opportunities, affecting your ability to recover economically after flood events?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

5. Do you have lack access to affordable insurance coverage to protect against flood-related losses?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

6. Does the high cost of flood mitigation measures, like home fortification, put you out of reach for your household?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

7. Does the lack of government financial assistance programs leave your community to shoulder the full economic burden of floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

8. Are you unable to build up adequate savings to withstand the financial impacts of repeated flood events?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

B. Social Vulnerability

9. Does corruption in local institutions impact your community's ability to receive timely assistance during floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

10. Do instances of bribery hinder the proper allocation of resources needed during flood emergencies?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

11. Does the existence of a patronage system affect your community's access to essential flood relief services?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

12. Does the high cost of healthcare affect your community's overall health and well-being during flood events?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

13. Is the absence of accessible healthcare centers a barrier to your community's health services availability during floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

14. Do inadequate sanitation facilities impact your community's health and well-being, particularly in flood-prone conditions?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

15. Are there language or cultural barriers that prevent your community from accessing important flood preparedness information?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

16. Does a lack of social cohesion and community networks limit your ability to collectively respond to and recover from floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

C. Environmental Vulnerability

17. Does your community's low-lying location increase the risk of flooding?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

18. Does the frequent riverbank erosion affect your community's safety and housing stability during floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

19. Do other adverse environmental effects, like deforestation or pollution, impact your community negatively during and after floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

20. Is your community located in a floodplain or other high-risk area prone to recurring flood events?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

21. Do you think, there is lack of early warning systems to prepare for impending floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

22. Does the degradation of natural flood buffers, like wetlands, increase your community's exposure to flood impacts?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

D. Physical Vulnerability

23. Does the risk of eviction due to floods affect your community's housing stability and overall security?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

24. Does household water scarcity during floods affect your community's daily activities and health?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

25. Does the lack of proper transport infrastructure affect your community's ability to evacuate and access essential services during floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

26. Are critical infrastructure issues, like damaged roads or electricity outages, a concern for your community during and after floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

27. Does the poor structural integrity of your home make it more vulnerable to flood damage?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

28. Are there accessibility challenges for the elderly or disabled in your community to safely shelter in place or evacuate during floods?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

29. Does the lack of secure land tenure make your household more vulnerable to displacement from flood events?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

30. Is your community's food supply chain disrupted during and after flood episodes, affecting food security?

o (Strongly Disagree) o (Disagree) o (Neutral) o (Agree) o (Strongly Agree)

Drivers of Flash Flood Vulnerability Assessment Questionnaire (Bangla)

নিম্নলিখিত বিবৃতিগুলির সাথে আপনার সম্মতির স্তরটি ১ থেকে ৫ পর্যন্ত একটি স্কেলে রেট করুন, যেখানে ১ বোঝায় "একেবারেই একমত নই" এবং ৫ বোঝায় "পূর্ণ একমত।"

Meaning of the options:

(১) (একেবারেই একমত নই) (২) (একমত নই) (৩) (নিরপেক্ষ) (৪) (একমত) (৫) (পূর্ণ একমত)

.....

১. আপনার এলাকায় কাজের অভাব কি বন্যার সময় আপনার ক্ষতির পরিমাণকে বাড়িয়ে তোলে ?

o (১) o (২) o (৩) o (৪) o (৫)

২. মজুরি না দেয়ার ঘটনা কি বন্যার সময় আপনার পরিস্থিতিকে আরো খারাপ করে তুলেছিল ?

o (১) o (২) o (৩) o (৪) o (৫)

৩. সামাজিক পরিষেবার (social safety net program) অনুপস্থিতি কি বন্যার সময় এবং পরে আপনাকে আর্থিক সমস্যার সম্মুখীন করেছে ?

o (১) o (২) o (৩) o (৪) o (৫)

৪. ক্ষুদ্রঋণ সুবিধার অনুপস্থিতি কি বন্যার ক্ষতিকে প্রভাবিত করেছে ?

o (১) o (২) o (৩) o (৪) o (৫)

৫. সাশ্রয়ী বীমা সেবার অভাব কি আপনাকে ক্ষতিগ্রস্থ করেছে ?

o (১) o (২) o (৩) o (৪) o (৫)

৬. বাড়ি সুরক্ষার মতো বন্যা প্রশমন (flood mitigation) ব্যবস্থার উচ্চ খরচ কি আপনার পরিবারের নাগালের বাইরে?

o (১) o (২) o (৩) o (৪) o (৫)

৭. সরকারি আর্থিক সহায়তার অভাব কি বন্যার ক্ষতির পরিমাণকে বাড়িয়ে তুলে ?

o (১) o (২) o (৩) o (৪) o (৫)

৮. বারবার বন্যার আর্থিক প্রভাব সহ্য করার জন্য কি আপনি পর্যাপ্ত সঞ্চয় গড়ে তুলতে সক্ষম?

o (১) o (২) o (৩) o (৪) o (৫)

৯. স্থানীয় প্রতিষ্ঠানে দুর্নীতি কি বন্যার সময় ক্ষতির পরিমাণকে প্রভাবিত করে?

o (১) o (২) o (৩) o (৪) o (৫)

১০. ঘুষের ঘটনা কি বন্যার সময় প্রয়োজনীয় বরাদ্দকৃত সম্পদ বিতরণে বাধা সৃষ্টি করে?

o (১) o (২) o (৩) o (৪) o (৫)

১১. পৃষ্ঠপোষকতা/ পরিবার প্রীতি ব্যবস্থার কারণে কি বন্যার ত্রাণ সেবাগুলি ব্যাহত হয় ?

o (১) o (২) o (৩) o (৪) o (৫)

১২. স্বাস্থ্যসেবার উচ্চ ব্যয় কি বন্যার সামগ্রিক স্বাস্থ্য এবং সুস্থতাকে প্রভাবিত করে?

o (১) o (২) o (৩) o (৪) o (৫)

১৩. সহজলভ্য স্বাস্থ্যসেবা কেন্দ্রের অভাব কি বন্যার সময় স্বাস্থ্য পরিষেবাতে একটি চ্যালেঞ্জ হয়ে দাঁড়ায়?

o (১) o (২) o (৩) o (৪) o (৫)

১৪. পর্যাপ্ত স্যানিটেশন সুবিধার অভাব কি বন্যাপ্রবণ অবস্থায় স্বাস্থ্য এবং সুস্থতাকে প্রভাবিত করে?

o (১) o (২) o (৩) o (৪) o (৫)

১৫. ভাষা বা সাংস্কৃতিক বাধা কি বন্যা প্রস্তুতির গুরুত্বপূর্ণ তথ্যের অ্যাক্সেসকে বাধাগ্রস্ত করে?

o (১) o (২) o (৩) o (৪) o (৫)

১৬. সামাজিক সংহতির অভাব কি সম্মিলিতভাবে বন্যার প্রতিক্রিয়া এবং পুনরুদ্ধারের ক্ষমতাকে বাধাগ্রস্ত করে?

o (১) o (২) o (৩) o (৪) o (৫)

১৭. আপনি কি মনে করেন আপনার এলাকার নিম্ন ভূমি অবস্থান, বন্যার ঝুঁকিকে বাড়িয়ে তোলে?

o (১) o (২) o (৩) o (৪) o (৫)

১৮. নদীতীর ভাঙন কি বন্যার সময় আপনার নিরাপত্তা এবং আবাসন স্থিতিশীলতাকে প্রভাবিত করে?

o (১) o (২) o (৩) o (৪) o (৫)

১৯. প্রতিকূল পরিবেশগত প্রভাব, যেমন বন উজাড় বা দূষণ, বন্যার সময় এবং পরে আপনাকে নেতিবাচকভাবে প্রভাবিত করে?

o (১) o (২) o (৩) o (৪) o (৫)

২০. আপনার এলাকার অবস্থান একটি floodplain ভূমিতে হওয়ায়, সেটি কি আপনার ঝুঁকিপূর্ণতা ও বন্যার প্রবণতাকে বাড়িয়ে তোলে ?

o (১) o (২) o (৩) o (৪) o (৫)

২১. আপনি কি মনে করেন, আসন্ন বন্যার প্রস্তুতির জন্য আগাম সতর্কতা ব্যবস্থার অভাব রয়েছে?

o (১) o (২) o (৩) o (৪) o (৫)

২২. আপনি কি মনে করেন যে প্রাকৃতিক জলাভূমির অবক্ষয় এ ধরণের বন্যা সৃষ্টির কারণ ?

o (১) o (২) o (৩) o (৪) o (৫)

২৩. বন্যার কারণে উচ্ছেদের ঝুঁকি কি আপনার আবাসন এবং সামগ্রিক নিরাপত্তাকে প্রভাবিত করে?

o (১) o (২) o (৩) o (৪) o (৫)

২৪. বন্যার সময় সুপেয় পানির অভাব কি আপনার দৈনন্দিন কাজকর্ম এবং স্বাস্থ্যকে প্রভাবিত করে?

o (১) o (২) o (৩) o (৪) o (৫)

২৫. সঠিক পরিবহন পরিকাঠামোর অভাব কি বন্যার সময় প্রয়োজনীয় পরিষেবাগুলির অ্যাক্সেসকে প্রভাবিত করে?

o (১) o (২) o (৩) o (৪) o (৫)

২৬. ক্ষতিগ্রস্ত রাস্তা বা বিদ্যুৎ বিভ্রাটের মতো গু সমস্যাগুলি কি বন্যার সময় এবং পরে আপনার সম্প্রদায়কে প্রভাবিত করে?

o (১) o (২) o (৩) o (৪) o (৫)

২৭. আপনার বাড়ির দুর্বল কাঠামো কি এটিকে বন্যার ক্ষতির জন্য আরও ঝুঁকিপূর্ণ করে তোলে?

o (১) o (২) o (৩) o (৪) o (৫)

২৮. আপনার এলাকায় বয়স্ক বা প্রতিবন্ধীদের জন্য নিরাপদে আশ্রয় নেওয়া বা বন্যার সময় সরে যাওয়ার চ্যালেঞ্জ আছে কি?

o (১) o (২) o (৩) o (৪) o (৫)

২৯. নিরাপদ জমির অভাব কি আপনার পরিবারকে বন্যার ঘটনা থেকে বাস্তুচ্যুতির জন্য আরও ঝুঁকিপূর্ণ করে তোলে?

o (১) o (২) o (৩) o (৪) o (৫)

৩০. বন্যার সময় এবং পরে আপনার এলাকায় খাদ্য সরবরাহ শৃঙ্খল কি ব্যাহত হয়, যা খাদ্য নিরাপত্তাকে প্রভাবিত করে?

o (১) o (২) o (৩) o (৪) o (৫)

Appendix B: Priority Ranking of the Drivers for Providing Recommendation Measures

Unions	Dimensions	Priority			Unions	Dimensions	Priority		
		1	2	3			1	2	3
Amirabad	Economic	Q4	Q7	Q3	Matabi	Economic	Q4	Q1	Q7
	Social	Q11	Q12	Q10		Social	Q11	Q12	Q10
	Environmental	Q21	Q18	Q17		Environmental	Q20	Q17	Q18
	Physical	Q27	Q28	Q29		Physical	Q29	Q27	Q28
Amjadhat	Economic	Q8	Q7	Q3	Mathu Bhuiyan	Economic	Q1	Q2	Q3
	Social	Q12	Q10	Q11		Social	Q11	Q12	Q10
	Environmental	Q19	Q20	Q17		Environmental	Q20	Q17	Q18
	Physical	Q27	Q23	Q28		Physical	Q29	Q27	Q28
Anandapur	Economic	Q1	Q3	Q4	Matiganj	Economic	Q1	Q3	Q6
	Social	Q10	Q12	Q15		Social	Q11	Q12	Q10
	Environmental	Q17	Q20	Q18		Environmental	Q20	Q17	Q18
	Physical	Q27	Q29	Q26		Physical	Q29	Q27	Q28
Bagadana	Economic	Q3	Q5	Q8	Mirzanagar	Economic	Q1	Q3	Q4
	Social	Q11	Q12	Q10		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q18	Q17	Q19
	Physical	Q26	Q27	Q28		Physical	Q29	Q27	Q28
Baksh Mohammad	Economic	Q2	Q4	Q7	Mohamaya	Economic	Q4	Q3	Q5
	Social	Q11	Q15	Q16		Social	Q11	Q12	Q10
	Environmental	Q18	Q17	Q19		Environmental	Q19	Q17	Q18
	Physical	Q29	Q26	Q27		Physical	Q26	Q27	Q28
Baligaon	Economic	Q1	Q3	Q8	Munshirhat	Economic	Q5	Q1	Q3
	Social	Q12	Q16	Q10		Social	Q11	Q12	Q10
	Environmental	Q17	Q20	Q18		Environmental	Q20	Q17	Q18
	Physical	Q23	Q27	Q29		Physical	Q29	Q27	Q28
Char Chandia	Economic	Q3	Q6	Q4	Nawabpur	Economic	Q13	Q7	Q3
	Social	Q9	Q14	Q10		Social	Q11	Q12	Q10
	Environmental	Q19	Q20	Q17		Environmental	Q20	Q17	Q18
	Physical	Q27	Q29	Q28		Physical	Q27	Q23	Q28
Char Darbesh	Economic	Q5	Q6	Q8	Panchgachhiya	Economic	Q1	Q3	Q5
	Social	Q12	Q10	Q11		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q20	Q17	Q18
	Physical	Q27	Q23	Q28		Physical	Q29	Q27	Q28
Char Majlishpur	Economic	Q1	Q5	Q3	Parshuram Paurashava	Economic	Q2	Q8	Q7
	Social	Q11	Q15	Q16		Social	Q11	Q12	Q10
	Environmental	Q19	Q20	Q18		Environmental	Q20	Q17	Q18
	Physical	Q29	Q27	Q28		Physical	Q29	Q27	Q28
Chhagalnaiya Paurashava	Economic	Q8	Q9	Q10	Pathannagar	Economic	Q1	Q8	Q2
	Social	Q12	Q10	Q11		Social	Q11	Q12	Q10
	Environmental	Q19	Q17	Q18		Environmental	Q20	Q17	Q18
	Physical	Q23	Q27	Q28		Physical	Q29	Q27	Q28
Chithalia	Economic	Q1	Q3	Q6	Purba Chandrapur	Economic	Q1	Q6	Q8
	Social	Q10	Q15	Q12		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q20	Q17	Q18
	Physical	Q29	Q26	Q27		Physical	Q29	Q27	Q28
Daganbhuiyan Paurashava	Economic	Q1	Q2	Q8	Radhanagar	Economic	Q1	Q2	Q3
	Social	Q9	Q12	Q10		Social	Q11	Q12	Q10
	Environmental	Q18	Q17	Q19		Environmental	Q20	Q17	Q18
	Physical	Q26	Q27	Q28		Physical	Q29	Q27	Q28
Darbarpur	Economic	Q2	Q4	Q1	Rajapur	Economic	Q8	Q3	Q4

	Social	Q11	Q12	Q15		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q20	Q17	Q18
	Physical	Q29	Q27	Q28		Physical	Q29	Q27	Q28
Dhalia	Economic	Q2	Q8	Q1	Ramnagar	Economic	Q2	Q8	Q7
	Social	Q11	Q12	Q16		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q20	Q17	Q18
	Physical	Q27	Q28	Q29		Physical	Q29	Q27	Q28
Dharmapur	Economic	Q6	Q3	Q4	Sanua	Economic	Q3	Q5	Q7
	Social	Q11	Q15	Q12		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q20	Q17	Q18
	Physical	Q29	Q27	Q28		Physical	Q29	Q27	Q28
Farhadnagar	Economic	Q2	Q3	Q8	Sarishadi	Economic	Q3	Q7	Q1
	Social	Q9	Q12	Q10		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q20	Q17	Q18
	Physical	Q27	Q28	Q29		Physical	Q29	Q27	Q28
Fazilpur	Economic	Q7	Q8	Q3	Sindurpur	Economic	Q4	Q5	Q3
	Social	Q11	Q12	Q10		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q20	Q17	Q18
	Physical	Q29	Q27	Q28		Physical	Q29	Q27	Q28
Feni Paurashava	Economic	Q3	Q4	Q8	Sonagazi	Economic	Q1	Q4	Q7
	Social	Q11	Q12	Q10		Social	Q11	Q12	Q10
	Environmental	Q19	Q17	Q18		Environmental	Q18	Q17	Q19
	Physical	Q23	Q27	Q28		Physical	Q29	Q27	Q28
Fulgazi	Economic	Q3	Q5	Q6	Sonagazi Paurashava	Economic	Q1	Q4	Q7
	Social	Q11	Q12	Q10		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q20	Q17	Q18
	Physical	Q29	Q27	Q28		Physical	Q23	Q27	Q28
G.M.Hat	Economic	Q1	Q5	Q2	Subhapur	Economic	Q1	Q3	Q5
	Social	Q11	Q12	Q10		Social	Q11	Q12	Q10
	Environmental	Q17	Q19	Q18		Environmental	Q20	Q17	Q18
	Physical	Q29	Q27	Q28		Physical	Q29	Q27	Q28
Gopal	Economic	Q9	Q8	Q5	Kazirbag	Economic	Q3	Q4	Q5
	Social	Q11	Q12	Q10		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q20	Q17	Q18
	Physical	Q23	Q27	Q28		Physical	Q29	Q27	Q28
Jailashkara	Economic	Q1	Q3	Q6	Lemua	Economic	Q1	Q4	Q5
	Social	Q11	Q12	Q15		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q18	Q17	Q19
	Physical	Q23	Q27	Q28		Physical	Q29	Q27	Q28
Kalidah	Economic	Q5	Q1	Q3	Mangalkandi	Economic	Q1	Q5	Q7
	Social	Q11	Q12	Q10		Social	Q11	Q12	Q10
	Environmental	Q20	Q17	Q18		Environmental	Q20	Q17	Q18
	Physical	Q29	Q27	Q28		Physical	Q29	Q27	Q28

Appendix C: Weight Generation Process

Factors	Indicators	Variables	Loadings in Component 1	Square the loadings	Sum the squared loadings	Normalize the squared loadings	Final Weights for Each Criterion
Social Vulnerability	Exposure	Population Density	-0.90	0.808	1.42	0.57	56.74
		Vulnerable age group	-0.79	0.616		0.43	43.26
	Susceptibility	Education	0.66	0.429	1.09	0.39	39.42
		Healthcare facility	0.54	0.287		0.26	26.40
		Poverty	-0.61	0.372		0.34	34.19
	Resilience	Shelter	-0.09	0.009	0.01	1.00	100.00
Physical vulnerability	Exposure	Slope	0.52	0.275	2.44	0.11	11.23
		Elevation	0.70	0.491		0.20	20.11
		Land use/landcover	-0.83	0.692		0.28	28.32
		Drainage density	0.58	0.333		0.14	13.62
		Geology	0.66	0.433		0.18	17.71
		Soil types	0.47	0.220		0.09	9.00
	Susceptibility	Previous Flood Extent	0.89	0.785	0.78	1.00	100.00
	Resilience	Access to Roads	0.67	0.452	0.45	1.00	100.00
Environmental Vulnerability	Exposure	Rainfall Intensity	0.49	0.242	0.24	1.00	100.00
	Susceptibility	Urban growth	-0.91	0.824	0.82	1.00	100.00
	Resilience	Recovery time to floods	0.03	0.001	0.00	1.00	100.00
Economic vulnerability	Exposure	Urbanized Area	-0.91	0.824	1.08	0.76	76.45
		Contact with River	0.50	0.254		0.24	23.55
	Susceptibility	Unemployment	0.83	0.691	0.69	1.00	100.00
	Resilience	Recovery time to floods	0.73	0.539	0.54	1.00	100.00

Appendix D: Correlation Assessment Results

Linear r (Pearson)					
	Overall Vulnerability	Economic Vulnerability	Environmental Vulnerability	Physical Vulnerability	Social Vulnerability
Overall Vulnerability		0.75	0.76	0.48	0.79
Economic Vulnerability	0.75		0.88	0.66	0.55
Env.Vulnerability	0.76	0.88		0.56	0.66
Physical Vulnerability	0.48	0.66	0.56		0.46
Social Vulnerability	0.79	0.55	0.66	0.46	

Spearman's D					
	Overall Vulnerability	Economic Vulnerability	Environmental Vulnerability	Physical Vulnerability	Social Vulnerability
Overall Vulnerability		4522.00	4838.00	9652.00	4546.00
Economic Vulnerability	4522.00		2814.00	5226.00	9156.00
Env.Vulnerability	4838.00	2814.00		7554.00	7174.00
Physical Vulnerability	9652.00	5226.00	7554.00		10152.00
Social Vulnerability	4546.00	9156.00	7174.00	10152.00	

Kendal's tau					
	Overall Vulnerability	Economic Vulnerability	Environmental Vulnerability	Physical Vulnerability	Social Vulnerability
Overall Vulnerability		0.55	0.54	0.32	0.56
Economic Vulnerability	0.55		0.66	0.53	0.32
Env.Vulnerability	0.54	0.66		0.41	0.46
Physical Vulnerability	0.32	0.53	0.41		0.28
Social Vulnerability	0.56	0.32	0.46	0.28	

Appendix E: Union-Wise Breakdown of Vulnerability in Feni District

No	Union	% Of Area																								
		Overall Vulnerability					Economic Vulnerability					Environmental Vulnerability					Physical Vulnerability					Social Vulnerability				
		Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High	Very Low	Low	Moderate	High	Very High
1	Amirabad	0.17	15.07	38.62	34.78	11.36	0.12	33.17	58.76	3.21	4.74	0.27	0.00	93.08	0.32	6.32	33.21	10.75	29.02	22.49	4.54	0.00	8.36	21.28	37.16	33.19
2	Amjadhat	0.15	6.87	29.23	44.40	19.36	0.00	0.18	0.10	80.61	19.10	0.00	0.28	0.00	20.69	79.02	54.86	6.48	33.15	5.34	0.17	16.30	54.70	20.19	6.44	2.37
3	Anandapur	81.29	15.28	1.98	1.17	0.28	54.97	40.86	3.02	1.14	0.01	62.60	33.59	0.01	3.12	0.69	21.63	13.84	31.80	25.90	6.83	64.83	31.63	2.59	0.93	0.01
4	Bagadana	7.06	19.26	25.42	18.11	30.14	0.27	29.65	33.02	10.19	26.87	0.86	55.40	6.51	0.42	36.80	30.53	20.97	28.89	15.55	4.06	0.01	14.58	23.73	32.58	29.10
5	Baksh Mohammad	0.04	36.04	35.79	26.07	2.06	0.00	0.11	28.49	62.54	8.86	0.00	0.11	0.09	93.61	6.19	49.79	11.98	25.63	12.31	0.29	50.80	43.67	4.02	0.78	0.72
6	Baligaon	45.05	33.21	9.66	6.73	5.34	78.65	5.12	14.90	1.32	0.00	83.13	0.34	0.62	15.82	0.09	19.19	20.61	37.82	14.08	8.29	0.00	17.61	29.60	36.02	16.77
7	Char Chandia	0.01	6.11	16.63	52.47	24.78	0.00	0.00	0.04	66.85	33.10	0.00	70.97	27.36	0.00	1.67	14.13	4.54	13.82	51.92	15.59	6.37	18.69	22.12	36.84	15.98
8	Char Darbesh	0.26	8.75	31.40	36.04	23.55	0.09	10.40	31.59	40.99	16.94	0.09	42.30	45.15	0.00	12.46	18.39	15.53	37.41	16.54	12.14	0.00	5.62	28.84	28.85	36.69
9	Char Majlishpur	25.64	37.55	16.51	6.33	13.97	5.64	36.41	6.86	4.80	6.38	74.97	6.17	0.07	17.91	0.89	6.83	18.83	46.01	18.53	9.81	1.69	26.27	31.23	24.86	15.94

10	Chhagalnaiya Paurashava	0.40	29.37	27.52	22.02	20.69	0.01	3.03	67.21	11.31	18.44	0.02	0.76	0.02	80.21	18.99	46.89	9.56	29.13	12.43	1.98	18.22	40.69	18.43	12.84	9.81
11	Chithalia	65.81	28.09	3.35	2.24	0.51	7.22	61.20	27.37	1.52	2.69	63.81	31.49	0.41	2.88	1.42	31.76	11.51	32.17	23.50	1.06	49.57	40.11	9.46	0.57	0.28
12	Daganbhuiyan	10.51	33.09	12.37	16.63	27.40	0.02	32.02	24.31	2.34	41.31	0.43	54.79	1.13	1.00	42.65	13.22	17.83	48.83	15.90	4.22	7.75	64.97	22.28	4.98	0.02
13	Daganbhuiyan Paurashava	36.83	8.20	9.99	40.49	4.49	0.21	9.16	0.48	8.26	3.80	44.85	0.10	0.02	54.32	0.71	5.72	18.68	57.37	14.64	3.59	21.31	76.15	2.51	0.01	0.01
14	Darbarpur	81.73	13.31	2.99	1.93	0.05	7.78	70.82	16.98	3.50	0.91	56.42	38.11	0.00	4.70	0.77	44.33	11.09	32.68	8.44	3.46	70.15	29.28	0.54	0.02	0.01
15	Dhalia	57.93	27.69	7.74	4.38	2.26	66.04	24.74	5.06	4.09	0.07	86.86	3.78	0.47	8.47	0.41	16.84	21.74	37.35	16.91	7.16	0.99	40.37	30.03	23.65	4.96
16	Dharmapur	32.62	25.54	16.46	15.05	10.32	63.43	6.51	23.85	6.03	0.18	4.56	51.73	11.65	5.65	26.41	47.38	18.27	23.61	9.80	0.94	0.53	16.46	21.57	37.21	24.23
17	Farhadnagar	10.78	45.63	30.55	9.01	4.03	0.15	64.89	26.45	2.94	5.57	0.00	0.59	54.87	36.03	8.50	48.78	11.23	30.53	7.66	1.81	6.52	48.57	36.82	6.08	2.01
18	Fazilpur	27.20	39.54	12.56	4.24	16.47	1.38	57.06	20.83	7.75	12.98	0.72	72.89	5.40	0.49	20.50	18.66	19.51	34.48	21.19	6.16	11.92	60.68	20.19	6.82	0.40
19	Feni Paurashava	1.19	10.37	11.17	9.15	68.13	1.10	26.59	3.84	60.15	8.33	0.77	0.48	13.77	16.05	68.92	15.74	11.94	57.21	13.77	1.33	0.00	4.62	16.94	33.98	44.45
20	Fulgazi	7.48	34.44	37.41	14.17	6.49	0.06	10.38	63.31	18.73	7.52	0.93	20.78	37.45	33.35	7.49	43.96	9.04	32.14	13.79	1.07	16.06	50.71	16.06	10.15	7.01
21	G.M.Hat	79.94	15.51	1.38	2.55	0.62	17.47	59.59	17.97	2.86	2.11	47.93	47.06	0.04	2.60	2.37	47.72	7.58	34.31	9.42	0.97	57.22	41.03	1.19	0.54	0.02
22	Gopal	0.19	6.25	30.40	36.28	26.88	0.13	21.32	58.55	6.43	13.57	0.24	0.34	0.05	84.98	14.39	35.30	15.55	30.88	15.85	2.42	0.01	11.58	24.95	33.13	30.33

23	Jailashkara	57.94	27.45	12.60	1.72	0.28	68.92	4.95	25.86	0.26	0.00	69.41	29.39	0.87	0.32	0.00	12.35	19.17	45.04	13.52	9.92	18.01	33.80	38.42	7.70	2.07
24	Kalidah	53.62	14.48	13.24	11.37	7.29	72.04	8.77	18.76	0.09	0.34	71.46	0.74	0.00	27.35	0.45	23.24	18.88	31.85	21.55	4.48	8.34	39.43	15.57	14.33	22.34
25	Kazirbag	41.03	27.38	8.84	16.28	6.47	74.82	10.02	14.95	0.20	0.00	45.89	28.45	0.56	22.11	3.00	27.95	15.59	33.63	19.55	3.27	0.57	20.26	18.78	30.79	29.60
26	Lemua	56.93	24.18	6.59	8.30	4.00	39.22	46.76	0.76	12.79	0.47	62.39	23.75	0.32	4.73	8.81	14.11	17.37	36.51	24.41	7.60	18.07	61.70	13.00	5.98	1.24
27	Mangalkandi	29.57	27.33	11.35	9.27	22.48	59.58	8.02	8.94	23.23	0.24	66.43	0.65	0.88	31.80	0.25	26.68	20.32	32.42	16.95	3.63	0.00	0.39	9.78	35.36	54.47
28	Matabi	77.18	13.53	6.70	2.43	0.16	66.87	23.18	7.18	2.73	0.03	46.41	43.13	0.08	7.82	2.56	29.82	14.14	34.07	15.69	6.28	49.10	48.20	2.59	0.10	0.01
29	Mathu Bhuiyan	61.49	5.88	17.66	13.81	1.15	30.05	35.18	2.30	28.98	3.50	66.19	0.35	0.01	33.26	0.20	32.43	28.08	23.07	13.31	3.10	21.14	74.11	4.69	0.04	0.02
30	Matiganj	3.89	26.34	28.90	12.73	28.15	0.52	58.85	11.69	14.50	14.45	0.52	36.16	34.37	0.28	28.67	32.17	17.34	33.78	15.30	1.41	0.00	2.50	26.64	28.24	42.62
31	Mirzanagar	24.89	46.27	23.27	3.20	2.37	0.00	0.21	43.13	49.10	7.55	4.17	38.38	49.73	0.35	7.37	44.27	8.06	32.38	14.98	0.31	87.54	11.74	0.63	0.08	0.00
32	Mohamaya	0.18	0.36	34.51	45.80	19.16	0.00	0.29	0.25	76.20	23.26	0.01	0.41	0.00	0.27	99.31	55.22	8.01	30.28	6.24	0.25	21.45	53.98	12.39	9.07	3.12
33	Munshirhat	56.96	36.60	3.18	2.17	1.08	0.49	50.75	44.01	1.25	3.49	26.51	67.94	0.53	3.42	1.60	39.71	7.38	31.13	19.27	2.51	67.71	28.13	1.62	0.36	2.19
34	Nawabpur	0.38	1.37	20.91	45.02	32.32	0.06	11.16	72.27	0.32	16.18	0.88	0.19	76.78	5.98	16.18	6.18	12.71	46.12	23.31	11.68	0.01	3.43	12.29	41.66	42.60
35	Panchgachhiya	38.52	22.39	5.72	15.11	18.27	53.36	11.60	24.63	10.41	0.00	63.50	1.37	0.21	30.02	4.90	12.56	20.89	40.75	20.88	4.91	1.36	27.80	15.71	28.54	26.59
36	Parshuram Paurashava	0.63	37.32	42.14	14.80	5.11	0.00	0.59	39.08	52.34	7.99	0.47	0.48	20.96	71.79	6.29	42.72	15.24	30.93	10.92	0.19	49.28	36.69	9.51	3.55	0.96

37	Pathannagar	57.23	31.23	5.41	4.21	1.92	60.71	30.55	6.21	2.16	0.37	1.17	90.93	0.00	0.35	7.55	25.01	11.95	33.33	25.09	4.62	21.03	64.45	10.69	3.22	0.62
38	Purba Chandrapur	84.23	9.43	5.74	0.59	0.01	67.13	19.16	5.73	7.88	0.10	86.46	0.02	13.18	0.34	0.01	19.60	24.81	32.02	16.02	7.55	72.90	26.37	0.72	0.00	0.01
39	Radhanagar	52.63	26.20	13.14	5.11	2.92	7.22	73.11	9.06	6.32	4.30	5.64	83.20	0.04	1.52	9.60	47.22	9.86	27.79	12.62	2.51	20.30	54.25	18.95	4.99	1.51
40	Rajapur	74.81	10.51	6.70	6.46	1.53	28.30	52.50	5.05	14.05	0.10	84.64	0.04	0.02	15.30	0.01	16.31	17.50	35.53	20.98	9.69	71.07	24.23	3.27	1.40	0.03
41	Ramnagar	49.21	12.15	11.66	24.74	2.24	0.47	48.50	12.31	25.04	13.69	60.73	0.52	0.11	38.53	0.12	20.37	21.43	37.73	16.98	3.48	34.14	64.49	0.87	0.48	0.02
42	Sanua	60.78	18.84	6.06	7.43	6.88	33.56	43.53	6.16	14.62	2.12	0.82	80.34	0.00	0.17	18.67	26.65	18.50	31.44	17.23	6.17	60.46	34.30	4.74	0.48	0.02
43	Sarishadi	53.38	18.90	9.40	9.29	9.03	62.51	15.15	10.46	11.82	0.04	64.89	12.74	0.00	12.98	9.38	23.54	19.80	29.94	21.11	5.61	17.10	33.68	17.34	10.22	21.65
44	Sindurpur	66.77	15.54	6.95	9.97	0.77	9.62	60.98	10.25	13.88	5.26	81.55	0.00	0.00	18.44	0.00	14.37	17.98	33.48	23.98	10.19	73.23	26.69	0.02	0.03	0.02
45	Sonagazi	0.72	22.79	34.83	32.59	9.06	0.00	7.60	49.73	39.83	2.84	0.02	36.24	60.57	0.31	2.85	21.97	19.19	22.19	24.76	11.89	2.62	26.64	35.38	24.37	10.98
46	Sonagazi Paurashava	0.00	0.79	13.80	45.45	39.96	0.00	4.64	47.30	31.23	16.82	0.05	8.18	71.74	4.03	16.00	7.66	15.41	43.49	22.76	10.68	0.00	0.40	12.12	33.42	54.05
47	Subhapur	38.21	38.57	15.42	5.05	2.74	19.31	67.06	4.04	8.80	0.80	28.42	61.64	0.00	3.69	6.24	48.92	8.35	36.29	5.18	1.26	5.07	22.76	29.29	31.53	11.34
48	Yakubpur	26.99	48.79	5.89	6.63	11.70	0.00	56.70	24.53	3.90	14.87	0.29	80.74	0.16	0.02	18.79	6.36	24.51	58.64	5.91	4.58	14.18	81.87	3.71	0.22	0.02

Appendix F: Survey Glimpse

Gobindopur Bazar Feni Sadar



Jayalaskarpur, Daganbhuiyan



Charkabir, Sonagazi





Shuvopur, Feni Sadar



Bashudebpur School Road, Rajapur, Phulgazi



Anandapur, Feni Sadar

Dholia, Sonagazi



Motiganj, Sonagazi



Dakshin Satbaria, Satbaria Bazar Road, Satbaria, Chhagalnaiya





Shuvopur, Feni Sadar



Eidgah Road, Fulgazi,



Bandhua Bridge Road, Amzadhat, Fulgazi



Purba Chandrapur,Primary School Road, Purbachandrapur, Parshuram