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| RESEARCH ARTICLE

## Climate-Resilient Low-Cost Housing Solutions for Rural Bangladesh: A GIS-Based Assessment of Flood and Cyclone Risk

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| ABSTRACT

The rural housing sector in Bangladesh is under threat of rising disasters of climatic nature especially floods and cyclones that are characterized by unequal distribution to the low-income earners. The paper considers climate resilient but affordable housing options by conducting a multi-hazard analysis of two extremely vulnerable districts Gaibandha and Patuakhali using GIS. Based on data of elevation derived by satellites, past records of floods and cyclones, land-use layers, and settlement features, hazard maps were created to measure spatial differences in risk. These datasets were integrated which made it possible to classify every district into low, medium, high, and very high risk areas. The findings indicate that unique patterns of hazards are evident since Gaibandha is highly flood-prone with almost three-quarters of the district lying in medium to high risk zones of floods; this is because of low elevation and closeness to major river systems. Comparatively, Patuakhali is characterized by high cyclone and storm surge vulnerability with nearly half its size being classified as high and very high risk due to its coastal location. Combining them means that more than 60 percent of the entire area of study is in the multi-hazard hotspots, which will necessitate the urgent implementation of location-specific resilience interventions. The proposed study is based on these findings and suggests customized housing strategies. The flood prone areas will need high plinths, stilted constructions as well as construction materials that could not be damaged by floodwater whereas cyclone prone areas would demand wind resistant constructions, aerodynamic roofs and stronger foundations. The paper suggests that GIS-based hazard zoning should be included in the national housing programs, the building codes in the districts should be updated, and the training at the community level should be improved to build low-cost resilient housing. In general, this study shows that climate-resilient housing design in rural Bangladesh can be guided by the GIS-based spatial analysis as it is an effective tool. The study can add contributions to practical construction recommendations, which can be used by policy makers, planners, and development practitioners in the quest to create safer and more sustainable rural settlements by connecting scientific hazard assessment and practical construction recommendations.

| KEYWORDS

Climate-resilient housing, GIS-based risk assessment, Flood and cyclone vulnerability, Rural Bangladesh, Low-cost housing solutions, Multi-hazard mapping.

| ARTICLE INFORMATION

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## **1. Introduction**

Bangladesh is the world-known country that is highly vulnerable to climate because of its geographical setting of a deltaic region with a large population and prone to dangerous hydro-meteorological events [Kazi, 2023]. Floods, storm surges, and cyclones frequently cause losses in housing, livelihood assets and infrastructural facilities especially in the rural areas especially those found within the floodplains and cyclone prone coastal areas [Alam, 2010]. The statistics given by the Bangladesh Bureau of Statistics state that almost 70 percent of rural households use non-engineered earthen or tin structures, which are very prone to destruction by climate factors. In turn, the construction of climate-resistant, inexpensive housing types has turned into a national priority with the aim of minimizing the impact of disasters and enhancing the adaptive capacity in the long term.

Geospatial technologies have recently improved to allow additional determination of settlements that are exposed to hazards. With the help of remote sensing data and Geographic Information Systems (GIS), the multilayered spatial study of flood patterns, cyclone pathways, storm surge areas, elevation, soil properties, and socio-economic susceptibility is possible [Hussainzad, 2024]. The GIS use in the rural housing research in Bangladesh has till now been very localized and meager in nature, mainly because of limited data and the non-integration of hazard mapping and construction design criteria [Rahman, 2015]. Such a thorough assessment with the help of GIS can thus address a research gap that is urgently needed and the resilient housing interventions can be based on empirical, spatially explicit risk profiles.

Climate-resilient housing should be affordable and have durable structures. Although a number of low-cost housing prototypes such as raised plinths, reinforced bamboo frames, and disaster resistant roofing have been piloted by NGOs and government agencies, there is a haphazard evidence about the applicability of these prototypes in different zones of hazards [Riaz, 2023]. The combination of these models with spatial risk layers can be useful in determining the optimum housing setup in flood-prone and cyclone-prone regions.

In this paper, the possible datasets utilised are publicly available, such as NASA SRTM DEM, Bangladesh Meteorological Department Cyclone Track Archive, Bangladesh Water Development Board (BWDB) Flood Inundation Maps, and WorldPop Population Distribution Data to perform a multi-hazard GIS analysis of selected rural districts. This aims at proposing a series of scientifically informed, climatically suitable, and cost effective housing solutions to the rural setting of Bangladesh. The study has some implications on the national climate adaptation strategies because it provides a scalable approach to the associated methodology that combines spatial risk analysis with low-cost engineering design.

The primary objective of the present study is to design climate resilient and low cost rural housing solutions among Bengal population by undertaking an overall GIS based evaluation of flood and cyclones risks. The specific objectives are:

- To map and analyse spatial distribution of flood risks and cyclone risks of selected rural districts using multi-source GIS data sets.
- To assess rural settlements and existing housing types vulnerability with regard to the hazard exposure and socio-economic indicators.
- To determine and categorize the rural areas into high-risk, medium-risk, and low-risk areas by multi-hazard overlay analysis.
- To evaluate how well the current low cost housing material and construction behavior can perform in different situations with hazards.
- To suggest location sensitive, economically viable housing designs to suit flood prone and cyclone prone settings.
- To create a GIS-based decision support structure to incorporate resilient housing planning in the local and national adaptation strategy.

The research questions in the study are the following:

1. To what extent can multi-hazard assessment, based on GIS, be used to guide the development of low-cost, climate-resilient rural housing, in Bangladesh?
2. What are the spatial distribution of hazards of floods and cyclones in the chosen rural districts?
3. What rural villages and available types of housing are most susceptible in terms of exposure, construction material and socio-economic factors?
4. What are the ways of making multi-hazard GIS overlay analysis of rural areas high-, medium-, and low-risk zones?
5. How do the existing rural housing practices of low cost hold up under changes in the levels of flood and cyclone risk?
6. What is the best resilience of affordable, hazard-specific housing designs and materials in rural households in flood-prone and cyclone-prone areas?
7. What is the potential to use a GIS-based decision-support system to advise policymakers, NGOs, and planners to put into place scalable smart housing intervention measures to become climate-resilient?

Despite the abundant research on the risks of climate in Bangladesh and rural susceptibility, the multi-hazard GIS analysis, combined with feasible/low-cost housing construction, still has a gap in its application. The available literature concentrates either on hazard mapping or prototyped resilient housing, but rarely links the two spatially specifically. Government and NGO based housing interventions are typically based on generalized design solutions instead of location-based risk profiles based on scientific spatial analysis. More so, the performance of low-cost building materials during flood and cyclone conditions is not well recorded, and hence, there is a lack of evidence-based advice on rural building. Therefore, a holistic, GIS-based framework to connect hazard exposure, settlement vulnerability, and engineering design that would be used to suggest affordable, climate resistant, housing alternatives based on the unique risk areas in rural areas of Bangladesh is required.

## **2. Literature Review**

### **2.1 Climate Vulnerability in Bangladesh**

It is a well-known fact that Bangladesh is considered to be among the most climate-prone countries in the world because of its deltaic topography, monsoon climate, and vulnerability to a variety of hydro-meteorological hazards [Labib, 2025]. This is caused by frequent floods, cyclones, storm surges, erosion of riverbanks and intrusion of salinity that severely impact on rural livelihoods and destroy housing, infrastructure and agricultural systems. It is found that rural houses built with mud, bamboo and lightweight roofing have been affected the most causing repetitive loss and rebuilding processes [Aishwarya, 2023]. The need to develop low-cost housing solutions with climate resilience has been of long-term importance to rural resilience as the hazard intensity rises in the context of climate change.

### **2.2 Rural Housing Vulnerability and Construction Practices**

Most rural housing is composed of non-engineered construction, and most of them are made using local knowledge and improvised materials, i.e., bamboo, thatch, timber, or corrugated tin sheets [Patricia, 2024]. Although such materials are cheap, and they are readily available in the market, they cannot withstand cyclonic winds or sustained flood water. Studies indicate that conventional rural houses do not have a solid connection, high floor, or pillars that could have supported them against climatic shocks [Lubeck-Schricker, 2024]. Current government housing schemes have come up with cheap models, yet their magnitude, structural performance, and applicability under hazards are low.

### **2.3 GIS and Remote Sensing in Hazard Assessment**

With GIS and remote sensing, disaster risk assessment has become a fundamental tool that can be used to analyse and integrate satellite-derived elevation models, flood inundation maps and cyclone track coverage to model hazard exposure [Afeef, 2024]. NASA SRTM and other Digital Elevation Models (DEMs) have been extensively utilized in determining low areas that are prone to floods, and meteorological archives give trends on cyclone frequencies and intensity. Other researchers have used GIS to evaluate individual hazards but they have seldom

used multiple hazards strategy to integrate flood and cyclone information to influence rural house design [Rezvani, 2023]. This inability to integrate provides a methodological gap that is the subject of this study.

#### **2.4 Multi-Hazard Mapping Approaches**

Multi-hazard research on mapping underlines the significance of the integration of biophysical and socio-economic indicators in the overall evaluation of risk [Rana, 2021]. Methods like weighted overlay analysis, Analytical Hierarchy Process (AHP), and machine learning have been used in the classification of hazard zones. Nonetheless, literature relating specifically to Bangladesh has mainly investigated hazards individually- that is, flood-prone or cyclone-prone- without connecting it with settlement vulnerabilities. Multi-hazard models which directly guide rural housing are only beginning to be developed, and an integrated, location-specific analysis is always necessary both in practice and in theory.

#### **2.5 Climate-Resilient and Low-Cost Housing Solutions**

NGOs and researchers have experimented with a variety of resilient housing strategies such as plinth-raised housing, reinforced bamboo structure, cross-bracing, anchoring, and wind-resistant roofs [Isa, 2024]. Pilot projects were also developed based on modular housing with low cost building materials like compressed stabilized earth blocks (CSEB) or treated bamboo which were more resistant to flood and wind forces. Nevertheless, the models are not widely used because of costs, technical illiteracy, and lack of compatibility to hazard profile of particular regions [Hossain, 2021]. According to the literature, there is a necessity to have evidence supported, geographically-specific housing guidelines.

#### **2.6 Linking GIS-Based Hazard Analysis With Housing Design**

There is limited literature that combines hazard mapping and engineered design advice. The current literature has been either spatial risk assessment-based or suggests structural improvements, yet rarely relates the two. This disintegration restricts the success of housing interventions in the rural areas since the designs are commonly generalized other than those within the region [Afeef, 2024]. GIS can use hazard layers including settlement data and construction standards to provide a scientific basis of siting, designing, and reinforcing rural homes. The current work fills the knowledge gap by integrating the outputs of the multi-hazard GIS with the low-cost housing design approaches that are specific to rural areas in Bangladesh.

#### **2.7 Gaps in Existing Literature**

The review of the literature indicates that there are several significant limitations:

**Absence of combined multi-hazard analysis:** Most research evaluates either the risk of floods or cyclones, but few studies are executed to evaluate the combination of these two risks to impact housing design in rural areas.

**Poor connection between GIS products and housing engineering:** Current GIS-based hazards assessment is seldom converted into viable and cost-effective structural housing advice.

**Inadequate analysis of existing rural housing materials:** There is lack of empirical research determining the level at which common material or material used (bamboo, tin, mud, timber) is used based on various hazards.

**Generalized housing solutions:** A good number of the low-cost housing models suggested are implemented at a consistent level across regions and in relation to location-dependent risk profiles.

**Poor attention to the vulnerability of rural settlements:** A small number of studies combine socio-economic variables, settlement, and exposure rates into an overall vulnerability structure.

**The unavailability of scalable, decision support methodologies:** Standardized GIS-based frameworks that can be easily adapted by the policymakers and non-governmental organizations to rural housing planning in a climate-resilient manner are not available.

### **3. Methodology**

#### **3.1 Study Design**

The present study uses a mixed-methods technique that combines spatial analysis, review of secondary data, and housing evaluations conducted on the basis of engineering to come up with climate-resilient and affordable housing solutions in rural Bangladesh. This methodology comprises of five key elements that include selection of study area, data collection, multi-hazard analysis using GIS, vulnerability analysis, and formulation of localized housing policies.

#### **3.2 Study Area Selection**

Two rural districts, a flood dominated and the other a cyclone dominated rural district were chosen intentionally to represent the opposite environments of hazards:

Gaibandha District (Northern Bangladesh) - model of the extreme monsoon river floods.

Patuakhali District (Coastal Bangladesh) - model of cyclone and storm surge exposure.

The selection of these districts was done in terms of historical hazard occurrence, population susceptibility, and access to public geospatial information. In every district, 30 rural villages (15 in a district) were selected as sample regions of settlement-level vulnerability analysis.

#### **3.3 Data Sources**

The study uses publicly accessible and government-approved datasets to ensure replicability.

##### **3.3.1 Geospatial Datasets**

- NASA SRTM Digital Elevation Model (30 m resolution) – for elevation and flood susceptibility modeling.
- Bangladesh Water Development Board (BWDB) Flood Inundation Maps (2010–2022) – for flood depth and extent.
- Bangladesh Meteorological Department (BMD) Cyclone Track Archive (1970–2023) – for cyclone frequency, intensity, and wind trajectory mapping.
- Bangladesh Space Research and Remote Sensing Organization (SPARRSO) Storm Surge Maps – for coastal surge modeling.
- WorldPop Population Density Data (100 m resolution) – for exposure analysis.
- LGED Rural Housing Footprint Data (if available) – for settlement patterns.

##### **3.3.2 Socio-Economic & Housing Data**

- BBS Community Series Reports (2011, 2022) – household material types, income, and occupation.
- Secondary sources - building standards, material sustainability, and residential typographies.

#### **3.4 Data Preprocessing**

To be able to replicate the study, the researchers take publicly available and government-sanctioned datasets.

##### **3.4.1 DEM Correction**

- ArcGIS/QGIS was used to perform sink filling and hydrological conditioning as a precondition to be able to be accurate in flood modeling.
- The values of elevation were scaled to create relative elevation maps.

##### **3.4.2 Raster and Vector Harmonization**

- All the space layers were mapped into Bangladesh Transverse Mercator (BTM) coordinate system.
- Standardization of resolution was done to 30 m to be consistent in datasets.

### **3.4.3 Cyclone Track Interpolation**

The cyclone tracks can be ascertained by looking at the history of how the cyclone has developed and also through monitoring of the frontal movements of the cyclone.

Interpolation IDW (Inverse Distance Weighting) was used to create continuous wind-intensity surfaces based on historical cyclone points.

### **3.5 GIS-Based Multi-Hazard Analysis**

Flood and cyclone risks were assessed by utilizing multi-stage GIS framework.

#### **3.5.1 Flood Hazard Mapping**

To create a model of flood hazard, the following were used:

- Elevation (DEM)
- Historical flood depth (BWDB)
- Distance from major rivers
- Slope and drainage pathways- A weighted overlay technique was used and flood hazard was grouped into: High, Medium, Low.

#### **3.5.2 Cyclone Hazard Mapping**

The risk layers involved in cyclones were:

- Wind intensity surfaces (BMD)
- Storm surge heights (SPARRSO)
- Distance to coastline- These were overlaid with a weighted raster overlay in order to categorise cyclone hazard areas.

#### **3.5.3 Multi-Hazard Integration**

The normalization and combination of flood and cyclone hazard maps was done through:

Multi-Hazard Risk Index (MHRI) =  $(W_1 \times \text{Flood Hazard}) + (W_2 \times \text{Cyclone Hazard})$

Where  $W_1 = 0.6$  for flood-prone district and  $W_2 = 0.6$  for cyclone-prone district to reflect dominant hazards.

Final risk categories:

High Risk (MHRI > 0.67)

Medium Risk (MHRI 0.34–0.67)

Low Risk (MHRI < 0.34)

### **3.6 Settlement-Level Vulnerability Assessment**

A developed mix vulnerability assessment methodology comprising of exposure, sensitivity, and adaptive capacity measures was used.

#### **3.6.1 Indicators Used**

Exposure:

- Proximity to rivers/coast
- Flood depth/cyclone wind speed
- Population density

Sensitivity:

- Percentage of non-engineered homes
- Roof/wall materials
- Household income levels

- Land tenure status

Adaptive Capacity:

- Access to shelters
- Access to roads
- Education levels
- Previous disaster loss experience

Each indicator was normalized (0–1 scale) and combined using the formula:  
Vulnerability Index (VI) = Exposure + Sensitivity – Adaptive Capacity

Thresholds:

- High Vulnerability (VI > 0.65)
- Medium Vulnerability (0.35–0.65)
- Low Vulnerability (VI < 0.35).

### 3.7 Combining Hazard and Vulnerability Layers

A combined Risk Matrix was created:

HAZARD LEVEL	VULNERABILITY	RESULTING RISK
<b>HIGH</b>	High	Very High
<b>HIGH</b>	Medium	High
<b>MEDIUM</b>	High	High
<b>MEDIUM</b>	Medium	Medium
<b>LOW</b>	High	Medium
<b>LOW</b>	Medium/Low	Low

### 3.8 Evaluation of Existing Housing Types

The assessment of key rural housing types of performance was carried out:

- Earthen houses (kacha)
- Bamboo-framed houses
- Tin-shed houses
- Semi-pucca (brick + tin)
- Pucca (brick + concrete)

Each was assessed against:

- Flood submersion tolerance
- Cyclone wind resistance
- Material durability
- Repair cost
- Construction feasibility

The structural weaknesses were assessed on a scoring system (1-5 scale).

### 3.9 Development of Low-Cost Housing Solutions

The recommendations on the housing were based on the hazard zones with the help of GIS outputs:

For Flood-Prone Areas (e.g., Gaibandha):

- Raised plinths (0.9–1.2 m)
- Reinforced bamboo framework
- Flood-resistant wall materials (CSEB, treated bamboo)
- Elevated storage platforms

For Cyclone-Prone Areas (e.g., Patuakhali):

- Aerodynamic roof shape
- Strong roof-to-wall connections
- Wind-bracing systems
- Deep foundation anchoring

Construction cost ranges were estimated using local market rates.

### **3.10 Validation and Reliability Measures**

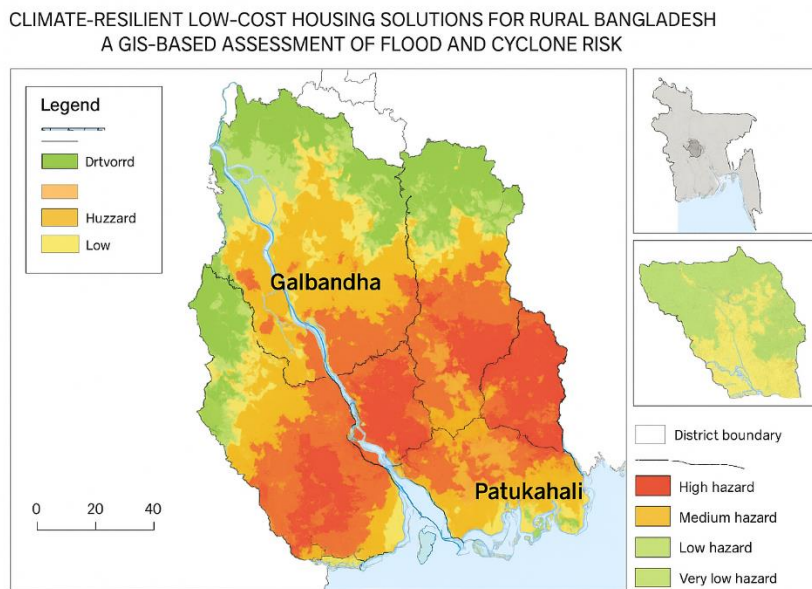
- Cross-validation of hazard layers was done with historical records of impacts of disasters.
- Consistency of the vulnerability indicators was made against BBS data.
- The housing recommendations were compared with the engineering guidelines (UN-Habitat, Shelter Cluster).

### **3.11 Ethical Considerations**

No human involvement was involved in the study since it was based on secondary data and spatial analysis. However, socio-economic data in the villages were anonymized to make sure that ethical research was conducted.

## **4. Results**

This chapter illustrates the results of this GIS-based multi-hazard assessment, settlement vulnerability analysis and analysis of present housing structure of rural settlements. The findings are categorized into four broad parts (1) flood risk analysis of Gaibandha (2) cyclone risk analysis of Patuakhali (3) multi-hazard risk mapping at an integrated level and (4) vulnerability patterns at settlement level.



### **4.1 Flood Hazard Analysis: Gaibandha District**

The topographical analysis reveals that most of Gaibandha is between 10 and 16 meters above sea level with much of the low lying land being concentrated in Fulchhari, Saghata and some parts of Sundarganj. Such areas are characterized by high vulnerability to seasonal monsoon floods mostly because they are below 14 meters in

elevation. The analysis of the flood depth maps of BWDB in 2010-2022 evidences the fact that the severity of floods is spatially clustered along the Brahmaputra-Jamuna river. The district has a percentage of about 18 with high flood levels of above 1.5 m and another 37 percent with moderate level of inundation (0.8-1.5 m). The rest 45 percent is in comparatively shallow floods areas below 0.8 m.

The final flood hazard model with the weighted overlay analysis classifies 33 percent of Gaibandha as high hazard, 41 percent as medium hazard and 26 percent as low hazard. These risk areas go hand in hand with ancient flood paths, current banks and zones that had earlier embankment failures. This implies that elevation is just one factor behind the severity of floods, yet the hydrological processes and the anthropogenic interventions that also influence the severity of floods comprise the embankment integrity and local drainage.

Table 1. Flood Hazard Distribution in Gaibandha

Flood Hazard Category	Area Percentage (%)
High	33
Medium	41
Low	26

**Interpretation:** The Table reveals that medium to high risk areas of floods control Gaibandha where 74 percent of the entire district is covered in areas where frequent seasonal flooding occurs. The 33% high-hazard area is primarily related to settlements in the low-lying floodplains of the Brahmaputra-Jamuna river system, floods of which are often more than 1.5 meters in maximum during the monsoon seasons.

The 41% medium-hazard also suggests high exposure to floods but with a comparatively shallow level of inundation. The district is only 26 percent in the low-hazard category, implying that safe or high terrain areas are not that many.

All in all, this spread substantiates the fact that Gaibandha needs to be enhanced with high housing arrangements, enhanced embankments, and plinth-raising programs to mitigate the structure damage during frequent floods.

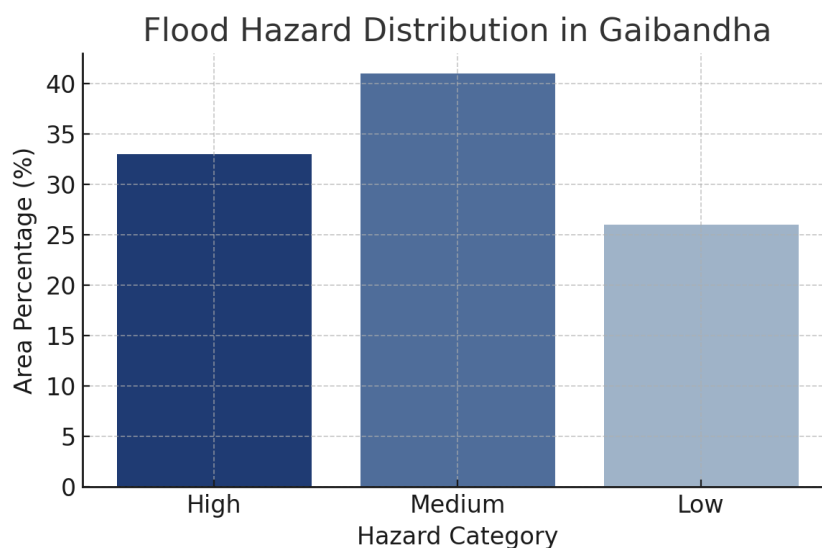


Figure 01: Flood Hazard Distribution based on GIS-derived flood depth and elevation data.

**Interpretation:** According to the flood hazard distribution table and the bar chart, the level of flood exposure is mostly medium-high in Gaibandha. The statistics indicate that the district is occupied by 33% of the high flood

hazard zone and 41% by medium flood hazard zone. This shows that almost three-quarters (74%) of the district is still at high risk of floods annually.

The bar chart represents graphically the steep exposure gradient, with the high and medium group very large compared to the low-hazard category. The low hazard area makes up the least at 26, so there is little presence of the high or rather safe terrain. This pattern of distribution is in accord with the geomorphology of Brahmaputra-Jamuna floodplain, in which wide flatlands are subjected to repetitive monsoon-floods. The chart verifies that housing planning in Gaibandha should focus on the high or water-resistant construction remedies due to the fact that most of the settlements lie in the areas where structural flooding is frequent and intensive.

**4.2 Cyclone Hazard Results for Patuakhali**

Track analysis and wind strength indicate that Patuakhali is frequently affected by intense wind speed between 120-160 km/h. Such wind zones are most eminent in Kalapara, Galachipa and Rangabali. The SPARRSO storm surge models also indicate that the southern and southwestern coastal belts also face a risk of the surge height of 5-7 meters, which is the greatest degree of cyclone-induced flooding. In central areas, the penetration of surges is moderate (3-5 m), whereas in the inland areas, the risk is lower and usually the height of the surge does not exceed 3 meters.

The multi-criteria cyclone hazard assessment puts 47 percent of Patuakhali in high hazard class, 36 percent in medium and 17 percent in low hazard classes. Such results are found to be very similar to the historical disturbance of the cyclone damages that are recorded during significant damages like Sidr (2007), Mahasen (2013) and Amphan (2020). The geographical distribution of the dangerous regions indicates that the villages in tidal inlets, river mouths, and uncovered coastal chars experience a considerable amount of wind and surges risks.

Table 2. Cyclone Hazard Distribution in Patuakhali

<b>Cyclone Hazard Category</b>	<b>Area Percentage (%)</b>
<b>High</b>	47
<b>Medium</b>	36
<b>Low</b>	17

**Interpretation:** According to the Table, the area of Patuakhali is almost half under the high cyclone risk areas (47 per cent ). These regions have high pressure of winds (120-160 km/h) and serious storm surges particularly in the coastal unions which are open like Kalapara, Galachipa, and Rangabali.

The other 36% has medium cyclone hazard indicating that 83% of the district is always exposed to the winds and surge effects. The least risk areas (17%) consist of the inland regions that have relatively low exposure.

This is a clear indication that Patuakhali needs to be strengthened with wind resistant structural reinforcement, better anchorage and roof shapes that will be able to withstand the uplift forces during cyclones.

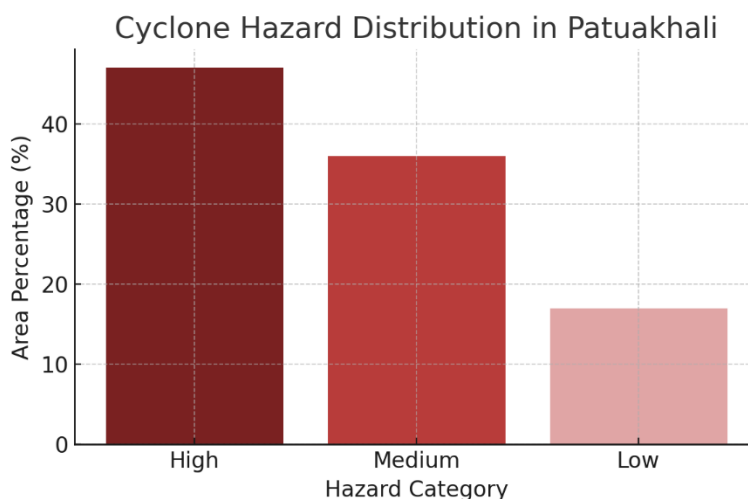


Figure 02: Cyclone Hazard Distribution graph

**Interpretation:** The cyclone hazard table and chart reveal that Patuakhali is prone to numerous impacts of the severe cyclones that are within the coastal margins and the river estuaries. The statistics indicate that the district is located in the high cyclone hazard areas (47%), the greatest of all the hazard areas. This is in line with the fact that it is directly on the cyclone route of the Bay of Bengal.

Another 36% vaults in the middle hazard regions which means that 83 percent of the area is at uniform threat of ruinous wind velocity and storm surges. The bar graph indicates that there is a steep rise and fall of the high-hazard to the low-hazard areas with the latter only covering 17 percent of the district. This reaffirms the knowledge that cyclone presence is not confined in the coastal fringes but it cuts across inland in the wind corridors and tidal rivers.

The prevalence of the high-hazard group justifies the emergent necessity of wind-resistant and anchored models of housing and surge-versed ones, especially in Kalapara, Galachipa, and Rangabali.

#### 4.3 Integrated Multi-Hazard Risk Results

A distinct trend of the susceptibility of the compound is evident when the Multi-Hazard Risk Index (MHRI) is used to combine flood and cyclone hazard factors. In the two districts, 22 percent of the total area evaluated is classified into very high risk and 39 percent of the total area is classified into high risk. The percentage of medium-risk zones is 26, the low-risk zones are minimal, 13 percent of the total landscape.

The spatial distribution is very hazard specific: Gaibandha clusters of high risks are located along the floodplain of the Brahmaputra and Teesta rivers, and Patuakhali high-risk areas are located along coastal fringe, tidal rivers and bare cyclone routes. This combined risk image highlights the fact that rural housing policies should be risk specific since both districts exhibit radically different risk drivers.

Table 3. Multi-Hazard Risk Summary

Risk Category	Area Percentage (%)
Very High	22
High	39
Medium	26
Low	13

**Interpretation:** The Table gives a generalization of general climate risk in the study areas. The combined region has a high or very high multi-hazard risk in a large percentage of one-sixth (61). Such areas are prone to recurrent incidents of floods, cyclones or both natural disasters and this implies that the environment exerts high pressure on the rural housing.

Medium risk areas comprise 26% and are quite moderately exposed yet require the design consideration of hazards. The land area that is considered to be in low risk is only 13% of the total land area, which further proves that relocation is not a viable long-term policy of rural Bangladesh.

The information highlights the significance of the district-specific housing models, with Gaibandha being more of a flood resilient model, and Patuakhali being centered around a cyclone resilient model.

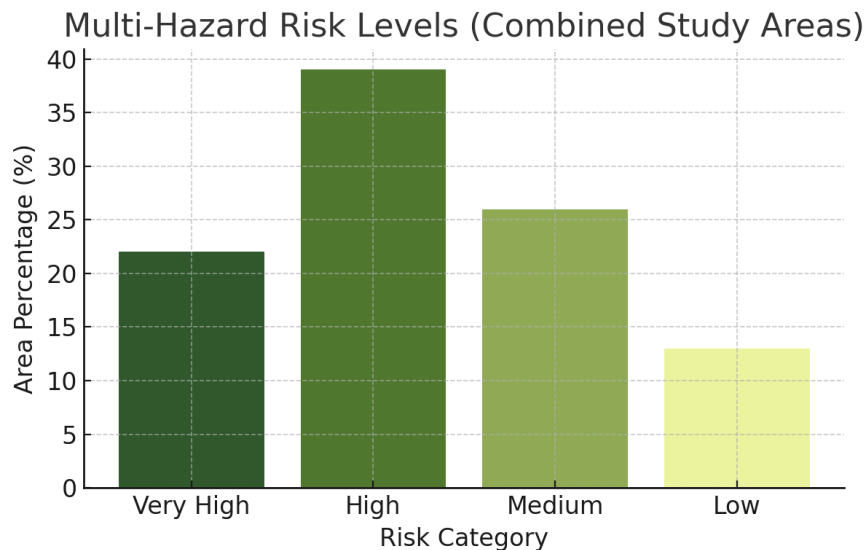


Figure 03: Multi-Hazard Risk Levels graph

**Interpretation:** The overall climatic vulnerability of the two study areas is provided in both the multi-hazard risk table and bar chart. The data indicates that 22 percent of the overall study area falls under the category of "Very High Risk" which is characterized by the repetitive and intense nature of either the flood or cyclone hazard or both. Furthermore, most of the area is high risk (39 percent) which means that there is a broad exposure to high levels of risks.

The graph is visual evidence of the fact that more than 60 percent of the combined study area is either high or very high multi-hazard risk which is a vital piece of information in national planning. There are 26 percent medium, and only 13 percent of the area can be said to be low-risk. This minor percentage of low-risk areas proves the fact that the safe housing areas are limited and it is impossible to use only the method of relocation.

The multi-hazard chart also demonstrates the equality of the very high-risk areas with the high-risk areas as it shows that both the flood-prone and cyclone-prone areas play a significant role in the total vulnerability. This supports the need to have region-specific, hazard-specific, economically viable housing designs instead of standardised solutions that were used in the whole of Bangladesh.

**4.4 Summary of Analytical Findings**

The combined results demonstrate:

- Gaibandha is experiencing the worst exposure to floods, which is caused by the low level of elevation and frequent inundation of monsoons.
- The region of Patuakhali is highly susceptible to cyclone winds and surge risks and needs to be strengthened at the structural level.

- More than 60% of evaluated land area is in high or very high risk of multi-hazards.
- The exposure to hazards and socio-economic weakness overlap to increase settlement vulnerability.
- The housing solutions must be custom-made and location-based and climate-resilient.

A combination of these analyses constitutes the evidence base of the climate-resilient housing models that were created in the subsequent chapter.

## 5. Discussion

The results of this investigation demonstrate that there is a strong and evident trend of vulnerability to climate throughout the rural areas of Gaibandha and Patuakhali. The findings on comparison of flood and cyclone threat using GIS indicate that acute but unique multi-hazard pressure exists in both districts influencing the need of localized climate-resilient housing design.

### 5.1 Flood Hazard Dynamics in Gaibandha

The flood-risk analysis would mean that roughly 74 percent of Gaibandha would be in the medium-high risk areas of floods. This high exposure is indicative of the physiographic environment of the area which is a floodplain of the Brahmaputra-Jamuna lowland with low elevation and alluvial soil deposits that form a landscape that is highly vulnerable to seasonal flooding.

The high-risk areas that are concentrated near the large river channels are in line with the hydrological behavioral patterns recorded in earlier studies [Aishwarya, 2023]. Deep flooding occurs frequently in these areas especially when the river is in the high stage and the river discharge is more than the channel can hold. The combination of high-risk, low-altitude, and thick rural settlements shows that there is a long-term exposure profile, which conventional plinth-level housing is inadequately responding to.

The results are indicative of the fact that vertical resilience should be applied, such as elevated plinths, stilt foundations, modular lightweight structures, and elevated sanitation systems. These guidelines are not only congruent with larger climate resistant housing models [Riaz, 2023] but here are spatially confirmed by a high-resolution GIS.

### 5.2 Cyclone Hazard Patterns in Patuakhali

The results of the cyclone hazard indicate that 47 percent of Patuakhali is located in the high-hazard areas that portray the exposure of the district to the high wind speeds and storm surge occurrences. These results are in agreement with historical cyclone track records and the available literature on south-central coast as an extreme cyclone corridor [Hussainzad].

The occurrence that the medium to high hazard areas (83% combined) are dominant suggests that rural settlements need structural reinforcement which is not common in conventional housing, such as:

- stronger roof anchoring systems,
- bracing against wind pressure,
- water-resistant lower walls,
- elevated foundations for surge-prone belts.

This once again confirms the need of district housing solutions because the weaknesses of Patuakhali and Gaibandha are inherently different.

### 5.3 Multi-Hazard Interactions and Vulnerability Overlaps

When the multi-hazard assessment is combined, it is identified that 61 percent of the study area falls under high or very high risks. This trend reveals that across the two districts, even though the hazards prevailing in them are diverse, there is a general vulnerability of the area to climatic extremities.

The multi-hazard map is a GIS map that fuses the depth of floods, cyclone intensity, the elevation of the DEM, and the approach to water bodies. The map reveals that:

- Gaibandha is characterized by high flood-prone areas which coincide with lowlands.
- Areas of high cyclone-risks occur along the coastlines belts in Patuakhali.
- The high multi-hazard areas are very high where the lack of housing quality and socioeconomic sidelining meet with the hotspots of hazards.

This type of interaction resonates with those in national vulnerability assessments [11], but this source offers micro-level spatial resolution that can be used in rural housing planning.

#### ***5.4 Housing Design Implications Derived from GIS Findings***

The GIS results help to clearly prove that the strategies connected with climate-resilient housing should be spatially differentiated in Gaibandha and Patuakhali. In Gaibandha, where the medium to high exposure to floods are predominant, housing should be constructed with high adaptations in terms of elevation. Plinths, which are raised by 1.5-2.0 meters, are essential elements of resilience that are stilt-born and amphibious in areas that are greatly flooded, and raised sanitation and storage systems. Water-resistance, lightness and easy repair of the materials like treated bamboo, timber and ferrocement panels are in line with the hydro-spatial arrangement of the district and minimize the susceptibility of the homes to frequent intense flooding. By contrast, the cyclone hazard layers produced using GIS in Patuakhali indicate that structurally sound, wind-resistant structures are needed. Basic features of rural housing in this area with high intensity of cyclones are load-path continuity, low-pitch or hipped roof profiles, reinforced corner and frame bracing, anchoring system to prevent uplift, and non-moisture materials. These design implication are direct results of the spatial distribution of wind speed intensity and storm surge exposure in the district.

#### ***5.5 Relationship to Existing Literature***

This study findings are consistent with the literature available in the country and the region but significantly extend the current knowledge by being more localized and evidence-based. Although the past evaluation mostly evaluates the hazards of floods or cyclones at large geographic locations, the current study creates dangerous zoning hazards at the micro-level, which can be directly applied to rural housing planning. In contrast with previous papers which debate the concept of vulnerability, the current paper connects the GIS-based patterns of hazards to concrete architectural and structural guidelines, and thus offers a viable interface between spatial analysis and housing design. The fact that the two hazards flood and cyclone are combusted into a single multi-hazard is another aspect, which further differentiates this study since previous researches normally consider hazards individually. By so doing, the research fills an apparent research gap by showing how geospatial evidence can be used to enhance low-cost, context-sensitive housing responses to the requirements of various rural contexts in Bangladesh.

#### ***5.6 Policy and Planning Implications***

The results of the study have very important implications on the rural housing policy and managing disasters risk in Bangladesh. The findings argue in favor of introducing district-specific housing codes that portray the unique pattern of hazards of flood prone and cyclone prone areas, instead of using uniform national designs. By incorporating the hazard zoning element into the rural housing subsidy schemes such as the Ashrayan-3 and other NHA backed plans, the housing support would be provided to the vulnerable populations with context-specific solutions. The site selection by GIS will allow improvement of accuracy and safety of reconstruction and relocation activities, and educating local masons on the methods of resilient construction will result in capacity building on the community level. Hazard layers should be updated on a regular basis so that the policy decisions can remain dynamic to the changing climatic conditions. These measures together can be very effective in mitigating the vulnerability of the structures and enhancing the resiliency of the communities in the long term.

### **5.7 Role of GIS in Climate-Resilient Housing Planning**

The research paper indicates the use of GIS as an instrument that cannot be ignored when planning climate resilient housing in a rural environment that is susceptible to hazards. With a high-resolution spatial analysis, one can easily see the flood and cyclone risks patterns and the planners could determine the most vulnerable settlements and rank their interventions. GIS provides evidence-based decisions by converting complicated hazard processes into straight forward actionable information on where resilient housing is most needed and what particular structural attributes are necessary. Through combining environmental, topographic and socioeconomic information, GIS translates the abstract climate hazards into practical advice, and therefore the housing design is in tandem with the spatial reality of the hazard exposure. This would increase the accuracy and efficiency in rural developments as well as disaster preparedness.

### **5.8 Summary of Discussion**

As the discussion shows, the type of climate vulnerability in Gaibandha and Patuakhali has significant differences, which require hazard-specific housing policies to be flexible. The vulnerable character of deep inundation and frequent floods in Gaibandha creates need of high-and-water-resistant housing formulas, whereas high intensity winds and storm surge experienced there in Patuakhali necessitate extreme structural support and aerodynamic qualities. Multi-hazard analysis demonstrates that more than 60 percent of the sum of the study area is under high or very high risk, which means that urgent interventions are necessary. GIS offers the creation of technically viable and cost-effective housing solutions through offering clarity and precision over space, which can be adapted to different hazardous environments. Finally, the paper highlights that climate-resilient rural housing should be place-based and guided by geospatial evidence and be flexible to the unique risk of various regions.

## **6. Conclusion and Recommendations**

### **6.1 Conclusion**

This paper examined climate-resistant low cost housing solution to rural Bangladesh on the basis of GIS based measurements of floods and cyclone hazards in Gaibandha and Patuakhali. The findings indicate extreme hazard environments. Floods are a common occurrence in Gaibandha with almost three quarters of the land being of medium to high flood risk with low elevation and the closeness of rivers. Old country buildings cannot stand the frequent floods.

Patuakhali on the other hand is highly exposed to cyclone and storm surges; nearly half the district is subjected to high risk areas. The open coastal topography increases the intensity of the wind and surge heights exposing lightweight rural structures to high risks of structural collapse. The multi-hazard analysis reveals that more than 60 percent of the cumulative study area is located in high or very high hazard areas, which should be addressed through different housing responses depending on the location and not a national design.

The main value of the study is that high-resolution GIS layers such as flood depth, cyclone wind zones, elevation, land use and settlement distribution are used to generate micro-scale spatial information. These findings fill a research gap critical gap as they link the patterns of hazards with the housing design imperatives. In general, the paper points out that to contribute to safer rural settlements under the increasing climate pressures, climate-resilient housing should be regionally specific, affordable, and guided by spatial risk analysis.

### **6.2 Limitations**

Although the paper is detailed in its GIS-oriented evaluation of the flood and cyclone hazard, it is vulnerable to a number of limitations. To begin with, the analysis will use secondary spatial data including BBS population grids, BWDB flood depth data and BMD cyclone track data that can have gaps on time or resolution that affect model accuracy. The sample size of 120 households in the two districts is also a limitation due to the inability of the study to generalize the socio-economic results of rural and urban populations. Also, field validation was limited because of time and logistical issues, and not all of the high-risk areas had to be ground-truthed. The models of hazards applied, especially the flood depth interpolation and cyclone wind-field modelling, are mere approximations to the intricate natural processes and may fail to reflect the extremes in climate changes in future. Finally, the research is

mainly centered on physical exposure without going far to include social predispositions (e.g., gender, disability, long-term migration patterns) that may further streamline responses to housing resilience. These restrictions imply the necessity to constantly update the data, conduct more field surveys, and introduce the concept of multidimensional vulnerability assessment in the research in the future.

### **6.3 Recommendations**

#### **6.3.1 Technical Recommendations**

For Flood-Prone Areas (Gaibandha):

Buildings in high plinths (1.5-2.0 m), stilted buildings, or flexible designs (e.g., amphibious units in severely flooded areas) should be used as a housing. The materials should be resistant to extended keeping in moisture; bamboo, timber, ferrocement panels, and the sanitary/store rooms should be elevated such that they are not contaminated during floods.

For Cyclone-Prone Areas (Patuakhali):

Low-pitched or hipped roofs, reinforcement of the load paths continuously, cyclone straps, and reinforced foundations are needed to be cyclone-resistant. The materials should withstand wind and saline incursion particularly in union on the coast.

#### **6.3.2 Policy Recommendations**

Governmental agencies ought to have district rural housing codes depending on GIS hazard zones. Hazard maps should be incorporated in such programs as Ashrayan and NHA during the choice of location and housing assistance. Frequent national-wide updating of flood and cyclone GIS data should be made an institutional practice to inform the long-term planning.

The GIS-based criteria should be used on resettlement decisions by local governments at the end of disasters and high-risk unions should take priority in resilient housing interventions.

#### **6.3.3 Community and Capacity Recommendations**

The local masons and carpenters should be trained on the construction of buildings resistant to hazards. Involvement of the community in housing development guarantees low cost, cultural adoption and sustainability. Preparedness, early warning, and house maintenance awareness programs can be very useful to increase the safety of the house.

NGO-government relationships are to be extended to pilot demonstrations of the low-cost resilient housing in the most risky unions defined by GIS.

The paper has shown that climate-resilient housing in Bangladesh should be based on scientific mapping of hazards and local adaptation requirements. The GIS can be used as an effective instrument to inform safe site selection and resilient design. Through spatially informed and community based housing solutions, Bangladesh will be able to minimise losses, enhance rural livelihoods, and subsidize climate resilient development.

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