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Capital Approach Integration in Flood Risk Reduction Assessment for Five Upazilas of Rajshahi

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Abstract: Frequent floods are one of the most serious natural hazards for a country like Bangladesh, which affects all its natural features in several cases: human beings, nature in the structure, and the livelihoods of human beings. Rajshahi district lies within the stretch of the Padma River. It suffers from different types of flooding during the monsoon due to riverside inundation, making it ever more vulnerable with geographical and hydrological exposures. Using a capital-based framework complemented with geospatial applications (GIS), the study undertook flood hazard and vulnerability assessments and risk appraisal in five upazilas of Rajshahi: Bagha, Charghat, Boalia, Paba, and Godagari. Moreover, the hydrologic data consideration includes land use, population density, economic resilience, and physical infrastructures as prime parameters in flood risk assessment. This data profiling classified Bagha as a very high-risk area (0.207) due to a high incidence of flood inundation and the lack of financial capital to sustain the community. The post-intervention simulation on Bagha shows a reduction of the risk index from very high to medium risk (0.098) through structural measures like elevated embankments and retrofitting high schools as flood shelters. On the same lines, Charghat, Paba, and consequently, were reclassified from medium to low risk, while Godagari remains very low risk due to its inherent socio-physical resilience. All these results translate to timely investments in flood infrastructure to reduce flood impacts, especially in vulnerable zones. The study provides a general visualization of scientific production in higher institutions using bibliometric analysis and also presents a scalable and data-driven approach to allocative prioritization for resource interventions in building resilience for flood-prone regions, providing policy actors with strategic information for effective resource allocation and adaptive response. This integration of geospatial analytics and multi-capital vulnerability assessment improves disaster mitigation approaches that further emphasise synergy between physical and socio-economic resilience in vulnerable riverine landscapes.

1. Introduction

Natural calamities mark the very life and death of Bangladeshis; every year, when the monsoon clouds draw near, millions arm themselves for an age-old battle. The rivers that are lifelines of the nation become agents of destruction, rising swiftly above their banks and engulfing wide territories. In the blink of an eye, a house is gone; in the twinkling of an eye, a crop is gone, sending the community into chaos. In a country where the Rivers Ganges, Brahmaputra, and Meghna flow, flooding is more of a certainty than an aberration.

Due to its deltaic formation from sediment deposition for centuries, the authorities generally consider Bangladesh one of the most flood-affected countries in the world (Brammer, 2014). With more than 80% of its land lying in floodplains, this country faces inundations every year, affecting 20–

25% of its territory; during extreme events, this figure rises to 60–70% (Dewan, 2015). Due to floods, millions get displaced, agricultural production gets crippled, and poverty is consolidated, costing the economy a whopping $1 billion every year (World Bank, 2020). One of the worst-hit areas is Rajshahi, where the Padma River, a distributary of the Ganges, regulates life and loss. Almost 40% of households here report flood-related losses every year, their fortunes somehow tied to the river's capricious flow (Islam *et al*., 2020).

The vulnerabilities of Bangladesh are embedded not only in the country's geography but also in the climatic situation. The monsoon rains constitute about 85% of the total annual precipitation in the country and, at the same time, coincide with the timing of peak river discharges, forming a deadly concoction (Gain *et al*., 2017). The climate, therefore, acts as another add-on uncertainty to intense rainfall and increased siltation and a rise of sea level that blocks drainage even more (Mirza, 2011). Water levels in the Padma have increased in the last 30 years by 1.5-2 meters; this prolongation of floods and increased destruction due to floods (Rahman *et al*., 2019). The consequences for the rural farmers of Rajshahi are profound. Rain-fed agriculture is the life of these farmers but is becoming increasingly unstable, thus locking them into a vicious cycle of loss and recovery (Parvin et al., 2016).

In Rajshahi, scars of flood transcend physical destruction to shatter livelihoods, disrupt services, deepen socio-economic inequities, and a survey carried out in 2020 reported that 68% of households among a cluster of heavily flood-affected households lose crops due to flooding, with almost one-third facing food insecurity for several months after flooding (Islam *et al*., 2020). Roads, schools, and health facilities sustain damage over and over again, isolating entire villages and subordinating recovery efforts (Alam & Collins, 2010). The most vulnerable, such as women, children, and marginalized communities, suffer the most as they are prevented from accessing early warnings and evacuation resources. Women, in particular, experience high levels of mortality during disasters, accounting for 45% of flood deaths in Rajshahi (Sultana, 2021). For many families, long-term effects are crippling: savings are spent, assets sold, and debts pile up, exacerbating inter-generational poverty (Mallick *et al*., 2017).

Engineering solutions—embankments, sluice gates, and drainage canals—have dominated Bangladesh's flood management strategy over the decades. These interventions, on the one hand, deliver short-term relief; but on the other, they left several roots of vulnerability unaddressed or in some cases even deepened the problems caused such as waterlogging and displacement due to the pre-emptive focus on structural defences while neglecting socio-economic resiliency in the case of the Flood Action Plan (FAP) of the 1990s (Bhuiyan, 2021). Moreover, traditional flood risk assessments, which predominantly include hydrodynamic modelling, neglected the most critical human dimensions of poverty, governance, and community adaptation strategies (Cutter *et al*., 2003). Recently, the research is calling for more holistic approaches, insisting that not only disasters occur from physical hazards but also inequalities in the allocation of resources and capacities (de Herve *et al*., 2022; Adger 2006; Sen 1999).

A capital-based framework is the alternative possibility, which views vulnerability through five capitals that interrelate-natural (land, water); physical (infrastructure, shelters); financial (savings, credit); human (education, health); and social (networks, governance)-a framework set for poverty and which should- in its application for disaster risk reduction-provide valuable insights for global learning (DFID, 1999). The common phrase "many say, many things show that communities with diversified portfolios of capitals are faster to recover from disasters: while financial reserves speed up the rebuilding process, strong social networks enable collective action (Adger, 2006)." The same has been reported in the Mekong Delta of Vietnam when elevated housing was combined with farmer cooperatives that reduced flood losses by 30% (Käkönen, 2008). Yet in rural floodplains, for example, Rajshahi, few have applied this due to a lack of data (Sarker *et al*., 2021).

In literature, Flood Risk was widely studied (more than 42000 articles on Scopus) from 1966 to the present, the "Flood Risk Reduction" > 5760 articles to indicate the importance of predicting and take some precautions to limit damages. But, only 524 documents, when GIS is added to keywords, to see the limited studies. So, it is important to perform a bibliometric analysis using Scopus analysis and complemented by VOS viewer to draw the map of authors and their collaborative teams (Öztürk *et al*., 2024; Sxx *et al*., 2021; Hassan *et al*., 2024; Hammouti *et al*., 2025). Based on countries generated by VOS viewer, **Figure 1** represents individual countries by the nodes (circles), and their sizes are typically indicative of the respective country's contributions or activity level in the field of Flood Risk Reduction. The United States has the highest activity level, with more than 1000 articles, followed by China and the United Kingdom. The lines between countries indicate the scientific collaboration. Furthermore, the thickness represented the intensity of the cooperation. **Figure 2** indicates the ten most countries publishing in this thematic as collected from Scopus.

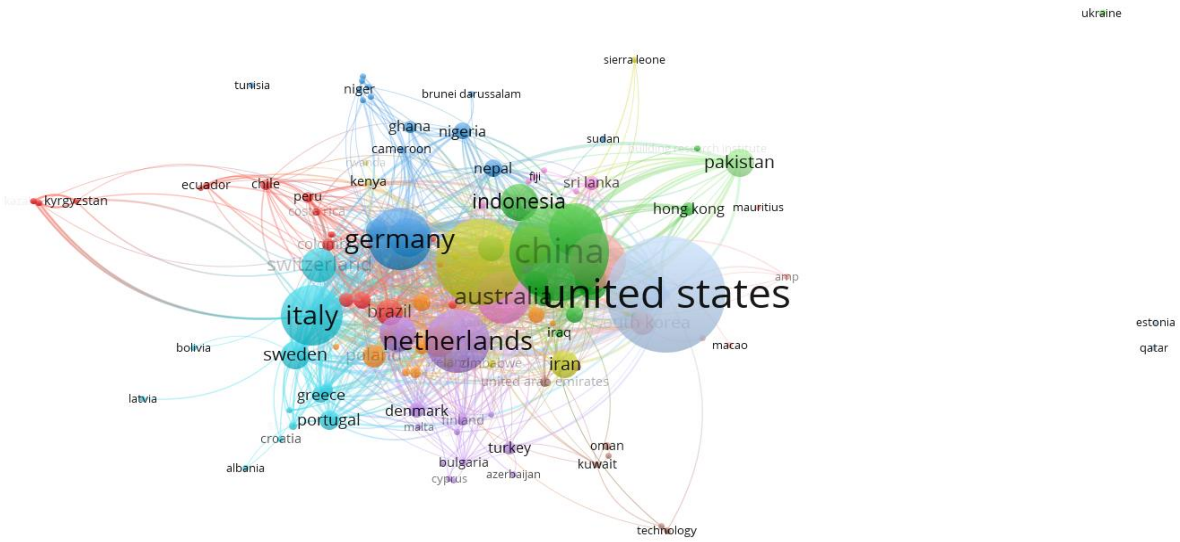

Figure 1. Global Collaboration Networks in Flood Risk Reduction Research

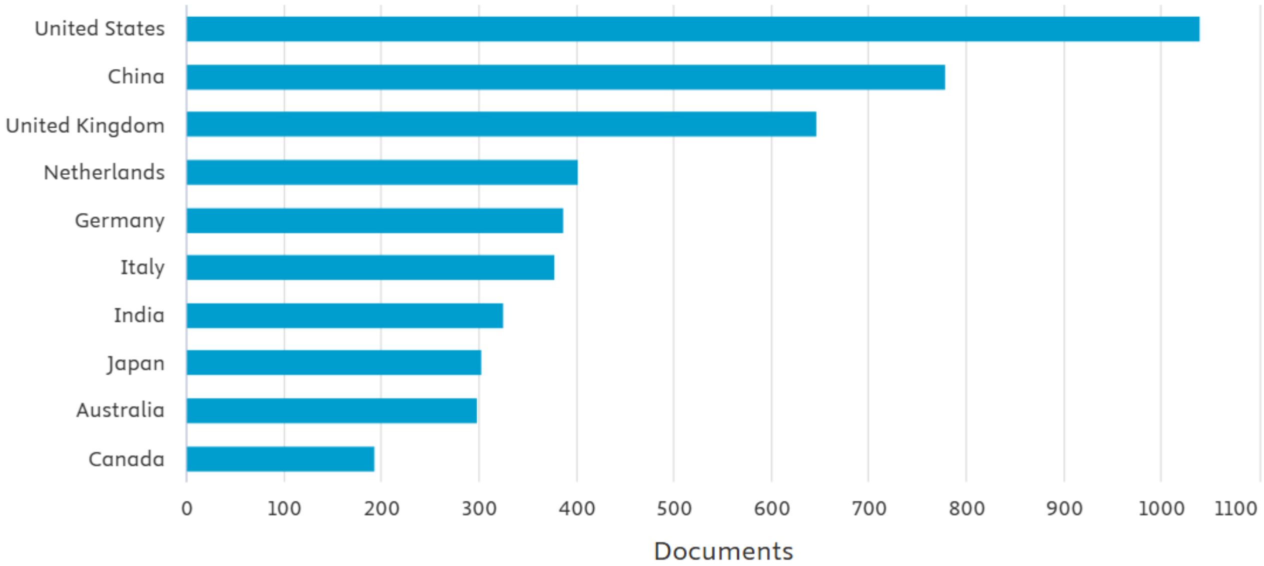

Figure 2. Top 10 Countries by Publication Volume in Flood Risk Reduction Research

Figure 3 identifies the top ten authors who published the most on this topic. These authors come from different countries as shown in **Figure 2**, including the United States, China, the United Kingdom, the Netherlands, Germany, Italy, India, Japan, Australia, and Canada. The researchers from the Netherlands, Aerts, J.C.J.H. and Botzen, W.J.W. are the most published authors.

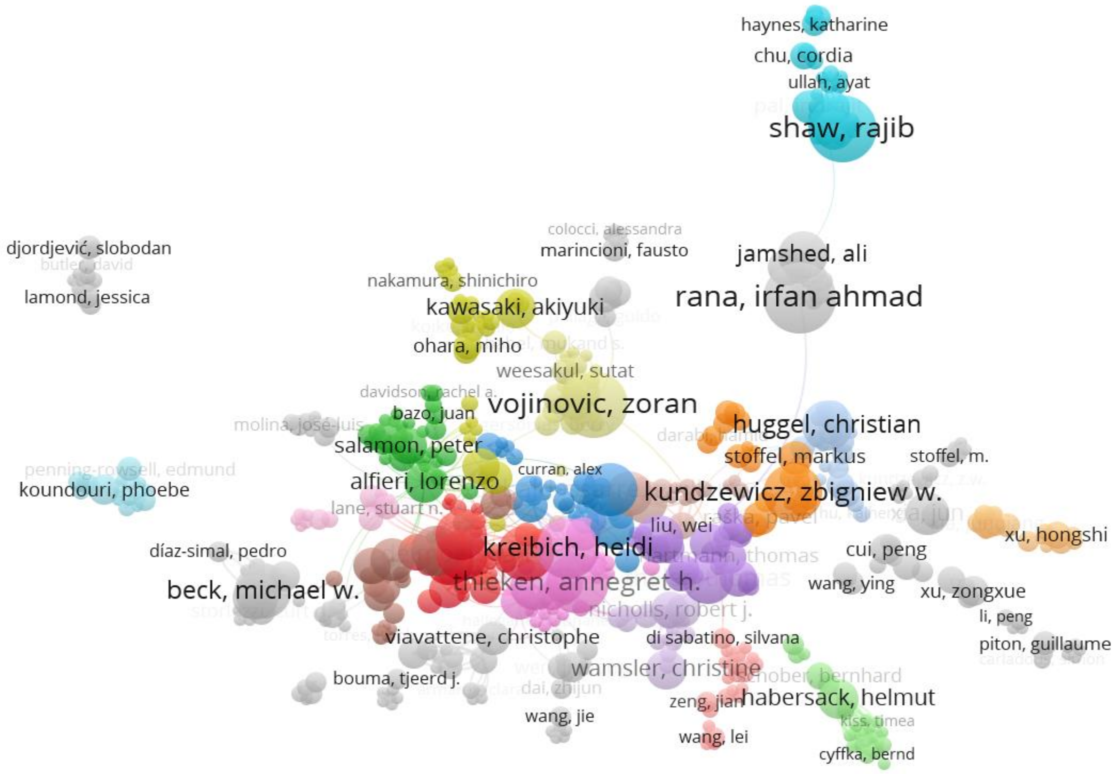

Figure 3. Co-authorship network visualization

Flood risk studies in Bangladesh have identified three critical gaps to be filled: the first is that almost all focus either on coastal or urban areas while ignoring riverine rural regions like Rajshahi (Ahmed *et al*., 2019), for example; while GIS, a tool combining many geospatial applications, is often used for hazard mapping, the integration of social or economic data into these tools has generally not been attempted to quantify vulnerability (Faisal *et al*., 2020); flood interventions, whether structural or non-structural, are frequently evaluated in a non-rigorous way, drawing mainly on anecdotal information or other qualitative assessments with little risk assessment applied (Hossain *et al*., 2022). It is hoped that this study will be able to address these gaps by assessing flood hazards, vulnerability, and risk over five upazilas that lie along the Padma River, utilizing GIS and a capital-based framework. Evaluating the effectiveness of structural (embankments) and non-structural (adaptive infrastructures) interventions. Provide evidence-based policy recommendations for flood resilience in northwestern Bangladesh.

2. Methodology

2.1 Methodological framework

The integrated flood risk framework begins with data gathering, which generates hydrological parameters (rainfall pattern, river discharge), socio-economic data (income, quality of infrastructure), and geospatial data (digital elevation models, soil-land use maps). The assessment of the flood hazard consists of hydraulic modelling, the historical knowledge of floods to delineate the potential high-risk zones, and estimation of peak flood magnitudes and flood discharge. Identification of exposed and vulnerable-at-risk populations (using census data), overlaid with the location of critical infrastructures, and assessing their economic resilience by indicators such as livelihood diversification and access to insurance eligibility are among the processes to this end. Following up is the assembly of these components, in which risk is calculated with elements to quantify the spatial extent of potential loss using a risk formula. Then comes the implementation of the mitigation strategy, where certain adaptive measures are planned, including building elevated flood shelters, strengthening embankments, wetland restoration, and early warning systems. Each adaptation intervention targets the identified vulnerabilities. The final stage is the result and comparative analysis, whereby risk reduction is measured using metrics such as reduced area of inundation, economic savings, or number of displaced persons, but the qualitative aspect assesses the preparedness level of the particular community. Based on that, this evidence-based iterative framework provides an avenue for stakeholders to assess cost-effective responses, thus ensuring that prioritized use of scarce resources enhances long-term resilience against escalated flooding threats in vulnerable, at-risk areas (**Figure 4)**.

2.2 Study area

The study area is in the northwestern part of the area within the Rajshahi Division, which has about 24°10'N to 24°30'N and several administrative zones. More important localities would be sub-districts (upazilas) or major settlements in this division, namely Godagari, Paba, Boalia, Charghat, and Bagha. Rajshahi Division is rather famous for agriculture, riverine ecosystem, and closeness to the Padma River, which further suggests the study areas are environmental, agricultural, or socio-economical by nature. Bangladesh is at the outer boundary, which indicates that these studies specifically lie in the northwestern region of the country with a tropical climate and alluvial plains. Such an area possesses strategic significance on account of climate change vulnerability, riverbank erosion, and agrarian livelihoods, while specific study objectives are implied by the geographic extent rather than stated explicitly.

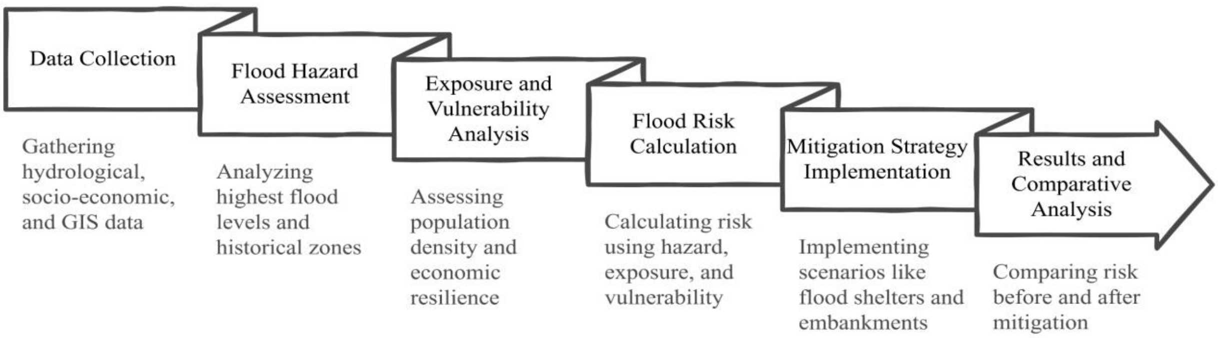

Figure 4. Methodological Framework for Flood Risk Assessment and Mitigation

In geographical terms, the study area has a north-south stretch of about 20 arcminutes (from 24°10'N to 24°30'N), which approximately translates to a latitudinal distance of about 37 kilometers. The study area is well-recorded and referenced from an academic standpoint; it applied WGS 1984, UTM Zone 46N-coordinates, which is standard for regional mapping in South Asia. Thus far, the scale indicates the mapped area is approximately 36 kilometers, an indication that it is of medium size and suitable for localized or comparative analysis. The grid lines laid on geodetic latitudes of 22°N and 28°N serve as references to geographic orientation; the main area of interest remains the 24°N band. This structure represents a systematic orientation to spatial inquiry, and focus is laid on precision in boundary demarcation attributable to land use and environmental features within the dynamic land use system of the Rajshahi Division (**Figure 5**).

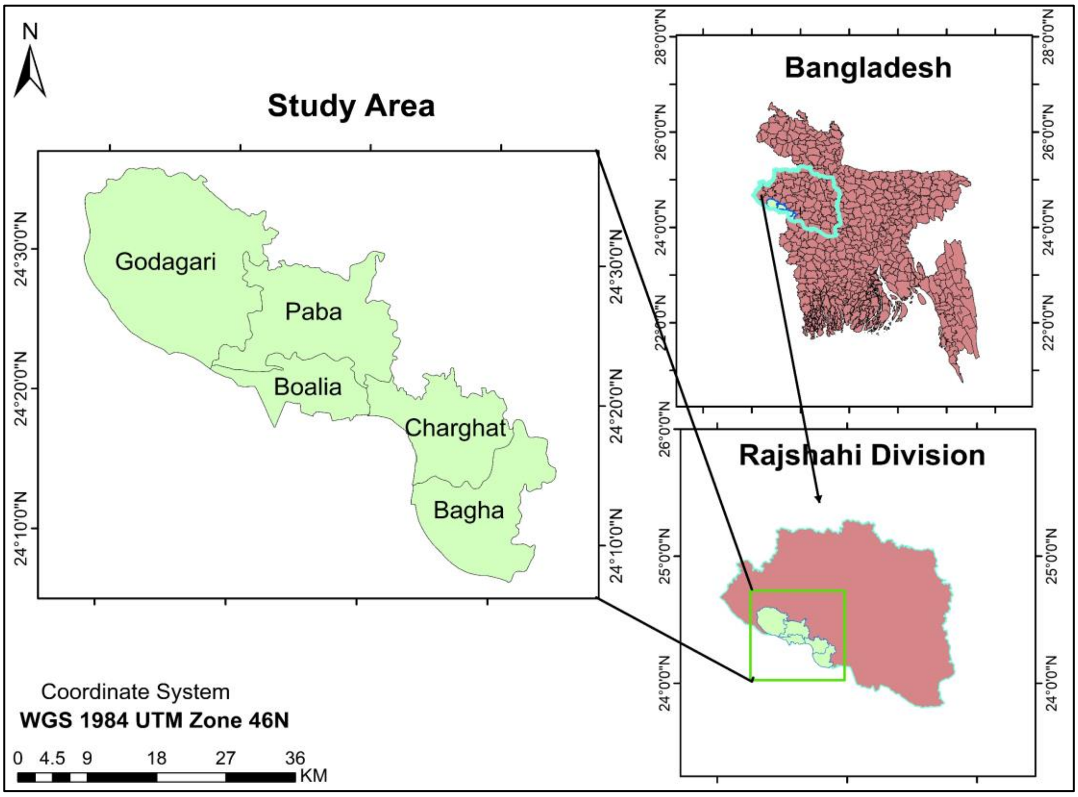

Figure 5. Study area

2.3 Data collection

The assessment of flood hazards, vulnerability, and risk in the five upazilas of Rajshahi involved the use of a multidimensional data collection framework in the study. The hydrological data source included, among others, historical flood records and the Highest Flood Level (HFL) of the Padma River sourced from the Bangladesh Water Development Board (BWDB). Measures of exposure included population density (people/km²) drawn from national census reports; Land Use Land Cover (LULC) classifications (e.g., built areas, crops, water bodies) were obtained from satellite imagery, i.e. Esri (Sentinel-2 10-Meter Land Use/Land Cover, 2023) and ArcGIS databases. The percentage of the population above the poverty line attained from district socio-economic surveys and government reports quantified financial capital. Data on different forms of physical capital, such as the number of high schools (these are identified as flood shelters) and the km length of embankment, were also gathered through local administrative offices and infrastructural inventories. This integrated approach captures both biophysical and socio-economic variables that are crucial in a holistic risk assessment.

The field data went through different challenges, such as making resolution differences between satellite-derived LULC classes and field verifications or getting real-time hydrological data during the non-monsoon period. The cross-validation for LULC involved the field survey to verify accuracy in LULC, while the other measures for real-time accuracy involved engaging BWDB to get updated readings of river gauges. Financial data limitations, like self-reporting biases of poverty surveys, were addressed by the triangulation of several datasets. Spatial data integration into GIS platforms further required the harmonization of the various formats (raster imagery, vector boundaries, and so on), which was achieved via ArcGIS tools. The ethical considerations included anonymizing census data and obtaining permission from local authorities. Resilient, rigorous, and iterative models were designed to ensure the robust generation of context-specific inputs to facilitate precise risk quantization and targeted intervention planning.

2.4 Water body

Figure 6 demonstrates water bodies from five upazilas, Bagha, Charghat, Boalia, Paba, and Godagari, in Rajshahi District, Bangladesh - important for the hydrology of the Padma River basin. Other water bodies, including rivers, floodplains, and seasonal wetlands, are important to flooding hazard modeling in this study. The Padma, which is the most important hydrological feature of these upazilas, divides the area by its rivers and their adjacent water systems, thus influencing flood vulnerability and land use patterns. The map has constructed spatial precision through the WGS 1984 UTM Zone 46N coordinate system, a scale bar (0-80 km), and a legend classifying water coverage. The data sources like Esri, USGS, and FAO provide trustworthiness, realignment with geospatial standards within flood risk analysis for integration of the hydrological variables into GIS-based risk assessments, and spatial inequality in presenting the water distributions that underlie exposure metrics of flooded vegetation and inundated cropland. This visualization puts flood hazards, embankment effectiveness, and land-use resilience strategies referred to in the study into context.

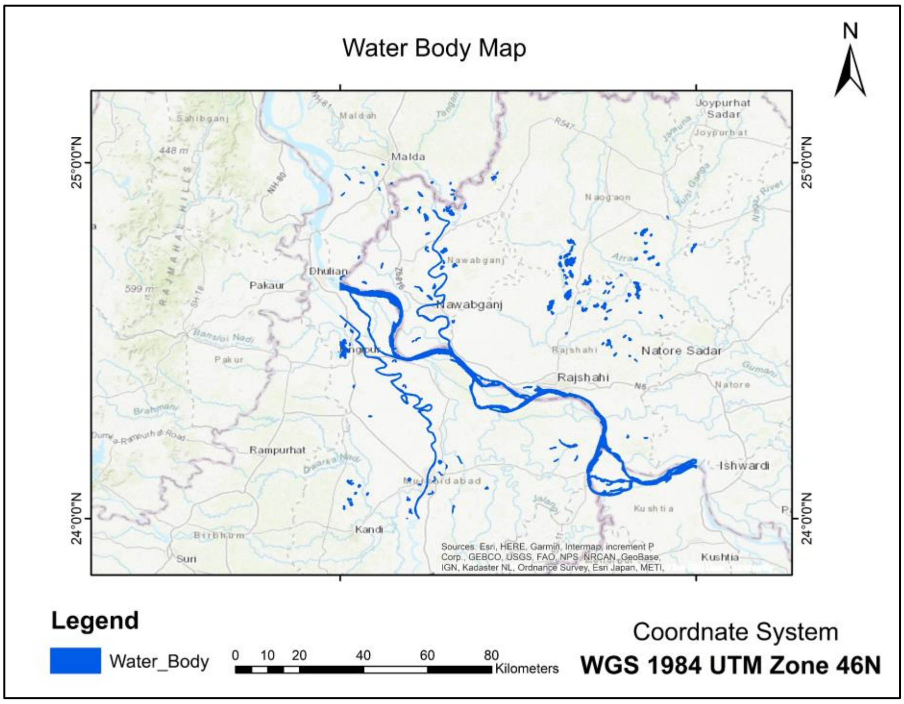

Figure 6. Water body of relevant areas

2.5 Flood hazard

Flood hazard calculation is an essential aspect of flood risk assessment since it quantifies the intensity of any prospective flooding, which provides the policy-makers with the basis for efficient mitigation strategies. Hazard is measured through the Highest Flood Level (HFL), which is taken to be the maximum water level attained in the area of interest during floods. This hazard assessment in the present study is needed specifically to highlight the most flood-prone upazilas in Rajshahi. Hence, the incorporation of hazard values with the exposure and vulnerability assessments leads to a more thorough flood risk evaluation. This assesses the near future requirements for relief measures in high-risk areas, such as the construction of embankments and flood shelters, the net benefits of which will lead to increased disaster resilience and preparedness.

2.6 Normalized value

Normalization provides standardized weights for a plethora of incoherent attributes - flood depth, population density, and financial resilience into a common scale from 0 to 1. This procedure would resolve the bias owing to units and make it possible to compare variables like exposure of agricultural land (hectares) and poverty rates (percentage). For example, variables like flood levels and number of schools are being converted into relative indices, overall contributing socio-economics and biophysical factors in certain proportions to risk computation. It also normalizes the asymmetry in data returned through raw figures (e.g., population density in urban compared to rural areas). The model calculates everything concerning its maximum value (i.e., reliance on the maximum observed value). It endorses relative risk rather than ensuring return for results to be skewed by magnitudes absolute. This activity is crucial for bringing together disparate datasets into one spatial risk map and works best in areas like Rajshahi, which presents diversity regarding flood drivers across administrative boundaries. The normalized value equation is below-

$$Normalized\ Value = \frac{[1 + \frac{(100-1)*(Value - Minimum\ Value)}{(Maximum\ Value - Minimum\ Value)}}{100}$$

2.7 Weighted value

Weighting assigns hierarchical importance to risk factors following their influence on flood outcomes. HFL and land use patterns get the highest weights due to their direct influence on the area of inundation and vulnerability to a community. For example, river depth (hazard) is given priority over financial capital as deeper floods menace more lives and property. Weights come from expert judgment, literature review, and regional flood dynamics to offer a model that is as realistic as possible in that priority. The step converts normalized values into contextually adjusted scores with emphasis on such important drivers as Padma River proximity or vascular density of flood-vulnerable infrastructure. Weighting ensures that the risk framework bids study appropriate to identify priority areas for interventions like embankments or shelters. The following equation-

$$Weighted\ Value = \frac{Assigned\ Weight}{Maximum\ Normalized\ Value} \times Normalized\ Value$$

2.8 Vulnerability & Risk

The very essence of risk involves a multiplicative fusing of hazard, exposure, and vulnerability. The hazard defines the election of flood physical extremes; exposure incorporates those persons and assets situated on flood-prone land; vulnerability defines the capacity of a certain community to withstand or recover from the disastrous incidents of flooding. To calculate sociological vulnerability, we take resilience and consider it as a composite of financial capital, such as income level or savings, and physical capital, for example, flood shelters or embankments. A community with low financial capacity or insufficiently developed infrastructure will present an enhanced level of vulnerability, thereby augmenting the possibility of incurring unfavorable effects from a hazard under moderate hazard situations. A case in point is the growing risk imposed due to a combination of high susceptibility for a risk-prone local environment with a high population density, weak embankments, and low poverty resilience.

The equation depicts the inherent risk to human life, welfare, and property in that such a risk is disproportionately magnified under conditions of high flood severity set upon a backdrop of human settlement density and low adaptive capacity. This brings to the forefront an interest in remedying the authorities-inhibiting behavior in a situation in which vulnerability-determined risks govern to the advantage of enforcement, stabilizing young engineers on upgrading the embankments of high hazards or elevating financial safety nets among impoverished localities. The inclusion of vulnerability allows the model to amplify socio-economic inequities since that must also be countered for just disaster planning in the Padma Basin.

$$Risk = Hazard \times Exposure \times Vulnerability$$

Where,

$$Vulnerability = 1 - Total\ Capital\ of\ the\ Community$$

3. Results and Discussion

3.1 Population density

The population density Map in Figure X indicates significant differences in spatial distribution across the five upazilas of Rajshahi District, Bangladesh, according to the WGS 1984 UTM Zone 46N coordinate system. Godagari averages 696 people/km², while Boalia stands at a maximum of 4,972 people/km², exemplifying settlements and urbanization. Some intermediate values are: Bagha, 995 people/km²; Charghat, 1,257 people/km²; and Paba, 924 people/km². A very high density at Boalia suggests a more urbanized center due to administrative and economic activities, whereas a very low density for Godagari is indicative of a more rural agrarian landscape (**Figure 7**).

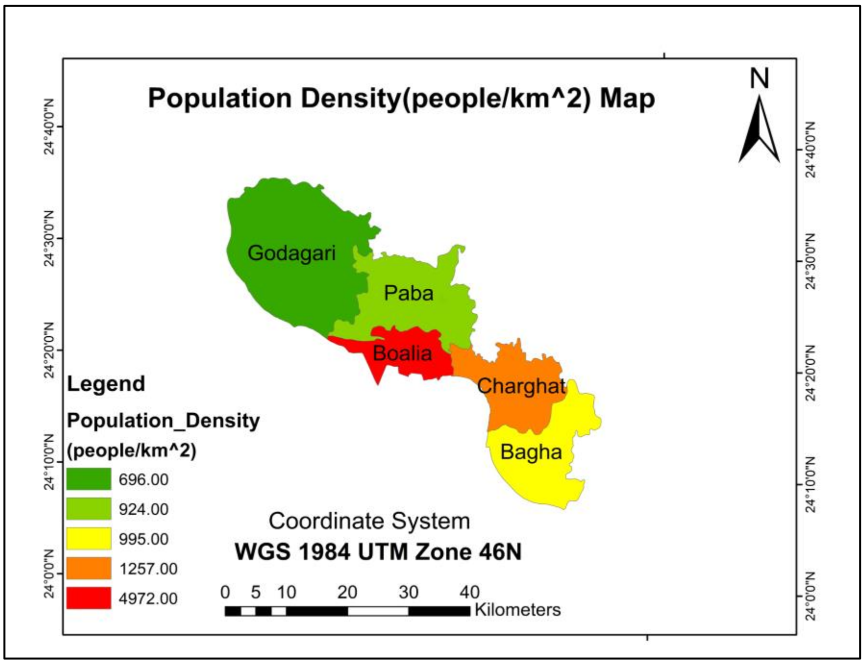

Figure 7. Population Density Visualization of Rajshahi's Five Upazilas

3.2 Land use land cover

The analysis of the Land Use and Land Cover (LULC) across five regions points out the remarkable area-wise dominance of seven factors (T-Tress, BA-Built Area, FV-Flooded Vegetation, C-Crops, W-Water, BG-Bare Ground, RL-Rangeland) in the land use systems, shown in **Figure 8**. In Paba, Crops (43%) and Built Area (40.83%) are the dominating factors, pointing to intensive agriculture and urbanization. Boalia has a mixed array with BA (24.51%), W (21.82%), and BG (20.76%) as the important components, suggesting diversified land use. In Charghat, Trees (39.07%) and BA (26.59%) dominate, signifying forested and semi-urban landscapes. Godagari has Flooded Vegetation as the sharpest prevailing feature, occupying 83.44% of the land, which greatly highlights wetland ecosystems. Contribution from Crops (12.58%) and Water (2.12%) is minimal; thus, the Godagari landscape presents an almost undisturbed character. Bagha is dominated by Trees (45.48%), followed by Crops (17.18%), and Built Area (13.43%), thus indicating afforestation with moderate cultivation.

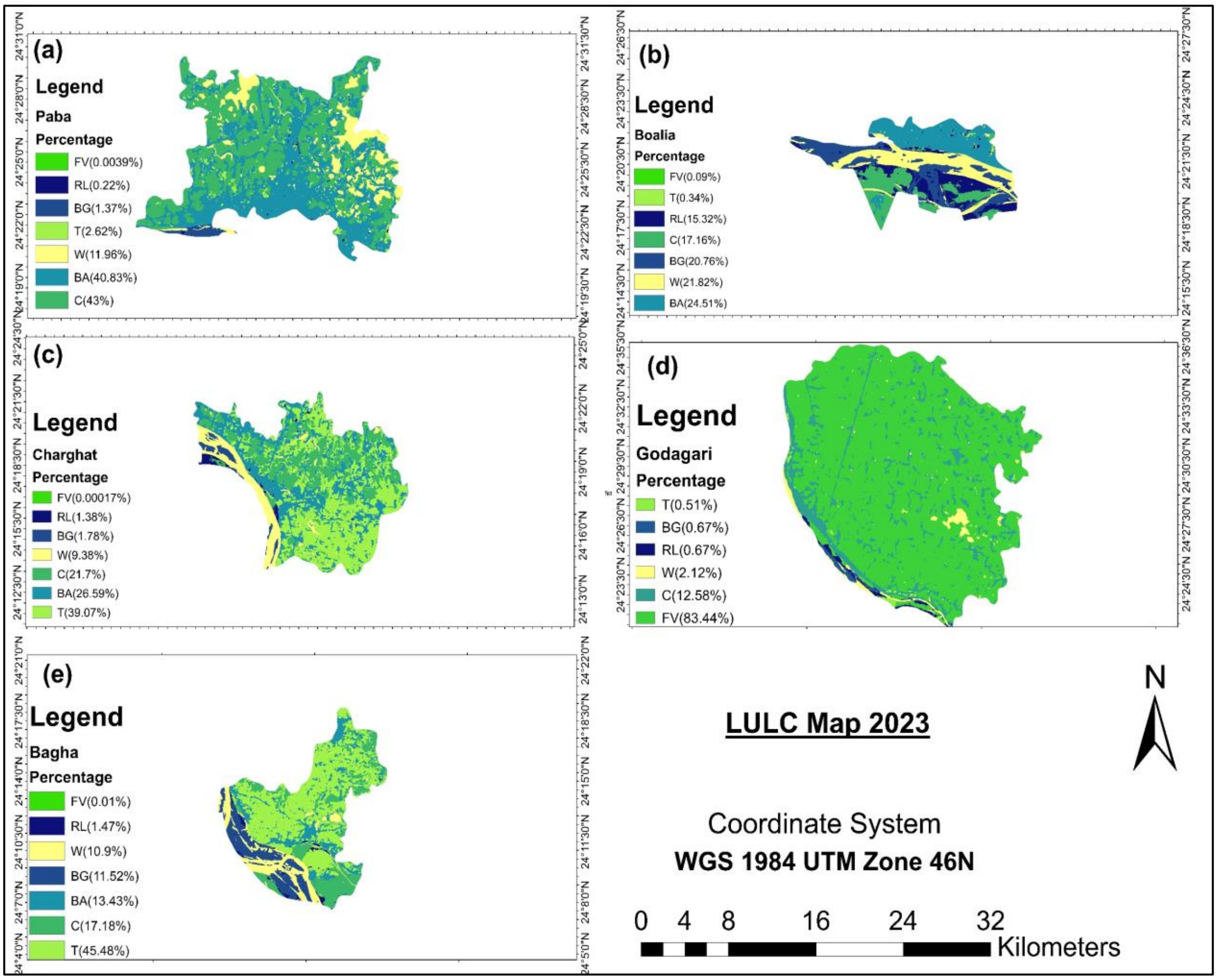

Figure 8. Land use land cover of Rajshahi's Five Upazilas

Comparatively, Tree peaks in Bagha and Charghat, while BA is sharply high in Paba and Charghat. The Water parameter is popular here in Boalia (21.82%) and Bagha (10.9%), in distinct contrast to Godagari, where it is virtually nil. Apart from Godagari, where it dominates almost wholly, FV finds little other space, showing the real ecological uniqueness of this particular wetland. BG (20.76%) is a major feature in Boalia and Bagha (11.52%), which hints at locations with very sparse vegetation and quite a bit of degraded land. Rangeland (RL) offers support for pastoralism in Boalia (15.32%), while the others ranged below 2%.

3.3 Flood hazard

The Flood Hazard (HFL) Map depicts inundation susceptibility for the regions within the study area, classified according to varying hazard levels, based on High Flood Level (HFL) measurements. Color codes have been used on the map: green referring to low flood hazard areas (actual 18.01-18.05m), i.e. Godagari, Boalia; yellow - moderate hazard (actual 18.09m) i.e. Paba; orange - high hazard (actual 18.10m) i.e. Charghat; and red - very high flood hazard (actual 18.52m) i.e. Bagha. The spatial distribution shows an increasing trend of flood vulnerability in the southeastern region. The map is presented in the WGS 1984 UTM Zone 46N coordinate system, with a scale bar showing distances up to 40 km. This classification is critical for flood risk management and land-use planning in the impacted areas (**Figure 9)**.

3.4 Risk assessment

The flood risk analysis of five upazilas in Rajshahi is depicted by a risk map prepared in ArcGIS (**Figure 10a**), and, as one might notice, there are differentials in spatial risk levels which result from the combination of hazards, exposure, and vulnerability. Among targeted areas, Bagha is the highest risk area classed as "very high risk", with a risk value of 0.21. Its elevated hazard level with an HFL of 18.52 meters, moderate population density of 995/km² measuring risk exposure, and high vulnerability score of 0.784 linked to limited financial capital (poverty above the line: very high at 80.9%) attribute its status as an area of high risk. Charghat and Paba fall into the "medium risk" category with values of 0.046 and 0.038, respectively; this combined both risk profiles of hazard-exposure but counteracted with relatively stronger financial resilience. Boalia also lies within "low risk" at 0.0136 despite being populated at a high density, registering 4972 individuals per square kilometer, where financial capital sufficiently limits vulnerability since 91% of people are found above the poverty line.

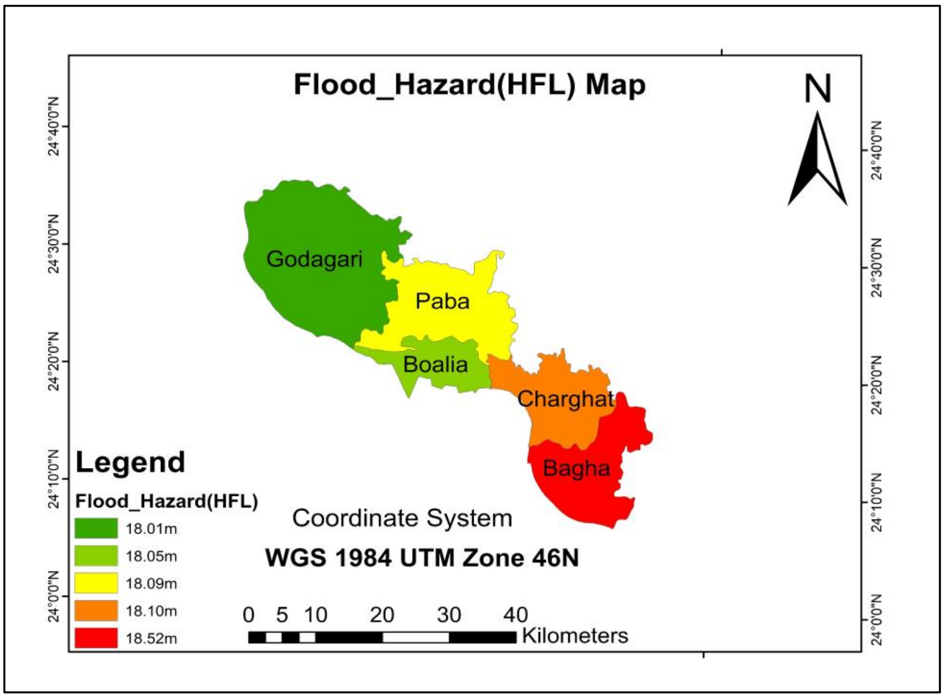

Figure 9. Flood Hazard of Rajshahi's Five Upazilas

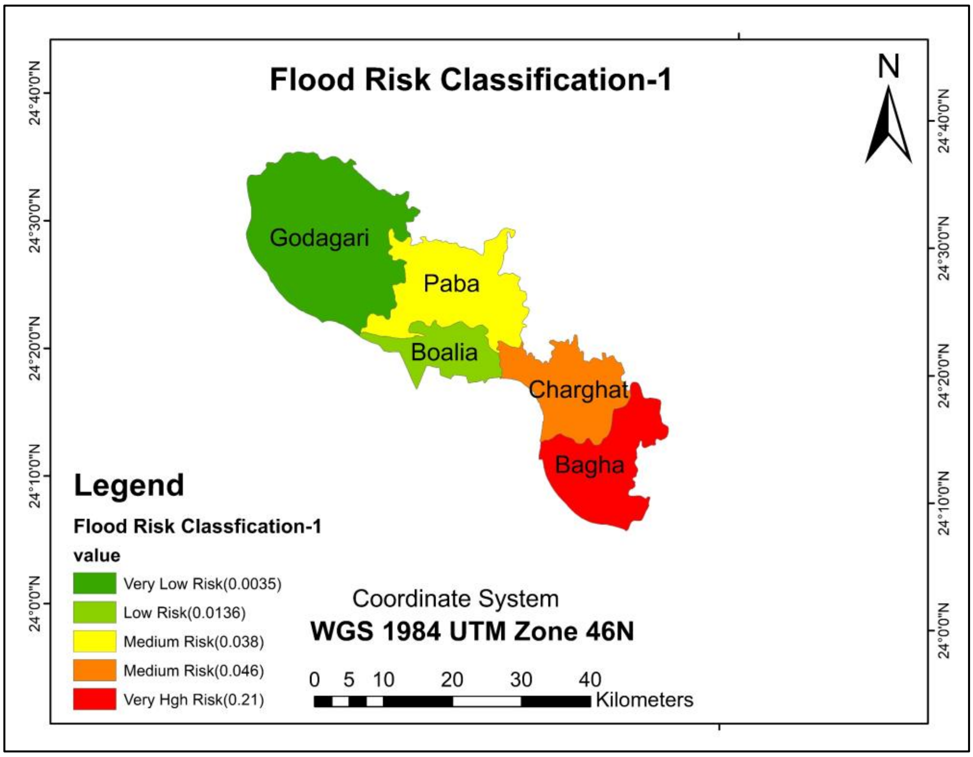

Figure 10a. Flood Risk Classification-1

On the other hand, Godagari is what one will call a strange case, as it falls into the classification of "very low risk" with about everything in the boundary of the HFL, which is equal to 18.01 m, and population density just below 696/km², but an extreme vulnerability rating (0.996) due to poor financial capital with 69.3% above poverty and great exposure of vegetated areas inundated with 83.44%. Thus, risk is not completely dependent on vulnerability but is made by other combinations of parameters. The entire map clearly shows spatial priorities: immediate attention should be given to Bagha for structural solutions and economic resilience programs toward Godagari. The analysis could have been strengthened with the incorporation of dynamic variables, such as seasonal hydrological variability or the efficacy of evacuation infrastructure. **Table 1** shows the risk categories concerning its risk assessment. **Table 2** comparatively assesses flood vulnerability, risk levels, and priority rankings across the various upazilas, all concerning set thresholds of risk.

Table 1. Category of flood risk

Risk Category	Risk value
Very Low Risk	< 0.01
Low Risk	0.01 to 0.035
Medium Risk	0.035 to 0.1
High Risk	0.1 to 0.15
Very High Risk	≥ 0.15

Of them all, Bagha presents very high vulnerability coupled with a very high risk (≥0.15), thus qualifying it as the top priority for flood management interventions. The upazilas of Charghat and Paba have similar characteristics; namely, these are moderately vulnerable with a medium risk (0.035-0.1), which consequently places them within the medium-priority tier. On the other hand, Boalia, despite being moderately vulnerable, only has a low-risk level (0.01-0.035); hence, it is classified as a low priority. Godagari has been classified as very highly vulnerable; however, the community experiences very low risk (< 0.01). This conditions it as the least priority area regarding flood mitigation initiatives. Ultimately, this classification will contribute highly to the types of targeted resource allocations and planning of flood preparedness activities (**Figure 10a**).

Table 2. Upazila-Wise Comparative Overview

Upazila	**Vulnerability**	**Risk**	**Priority**
Bagha	High	Very High Risk	Highest Priority
Charghat	Moderate	Medium Risk	Medium Priority
Boalia	Moderate	Low Risk	Lower Priority
Paba	Moderate	Medium Risk	Medium Priority
Godagari	Very High	Very Low Risk	Lowest Priority

To counter the risks, the model applied more physical capital- high schools as shelters against floods, shown in **Table 3** and then adjusted the weights for the financial factor and physical capital. Normalized counts of schools were included in the capital to reduce its vulnerability. That gave Bagha from Very High (0.207) to High (0.144); this was due to adding 49 shelters into its capitals. Charghat and Paba shifted from Medium to Low Risk (0.019 and 0.024, respectively) because of such shelters enhancing resilience: 65 shelters have made it possible for Charghat to switch, while Paba has 50 shelters. Boalia remained at Low Risk (0.014) with slight changes, while Godagari risk remained minimal (0.002), with 56 shelters, as caution was more natural than hazardous (**Figure 10b**). This became a case for how infrastructure could mitigate vulnerability, especially in high-exposure zones. It proved to be an effective risk mitigation in terms of targeted shelter provision.

Further risk reduction was evaluated with additional physical capital, the introduction of embankments (11-25 km) and redistribution of weights (embankments, 0.2). Normalized embankment lengths were added to capital metrics, further lowering vulnerability. Bagha saw the risk reduced to Medium (0.098) at 23 km embankments, whereas Charghat and Paba improved incipiently (0.013 and 0.024). Godagari remained at very low risk (0.002) with its offsetting 25 km embankments on a high-vulnerability background. Boalia slightly raised the risk (0.011) owing to ineffective embankment in high-density zones. The analyses showed embankments exercise a dual role: risk reduction and capitalizing improvement, mostly in flood-prone areas like Bagha (**Figure 10c**).

Table 3. Upazila-Wise Physical Capital and Embankment Overview

Location	**Physical capital (no of high school for flood sheltering)**	**Embankment (km)**
Bagha	49	23
Charghat	65	17
Boalia	25	18
Paba	50	11
Godagari	56	25

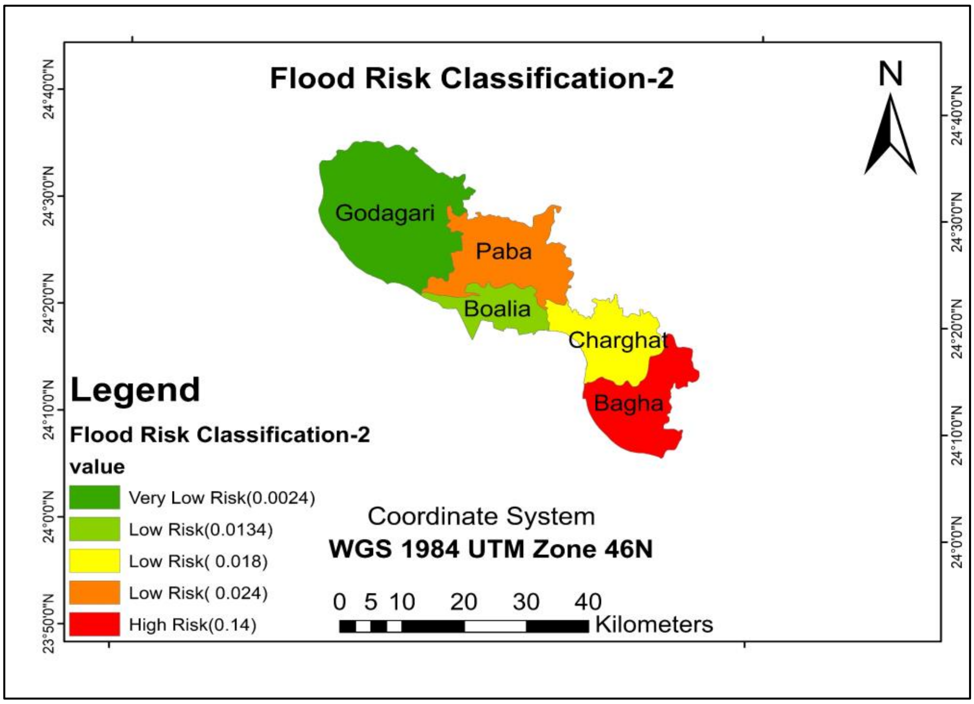

Figure 10b. Flood Risk Classification-2

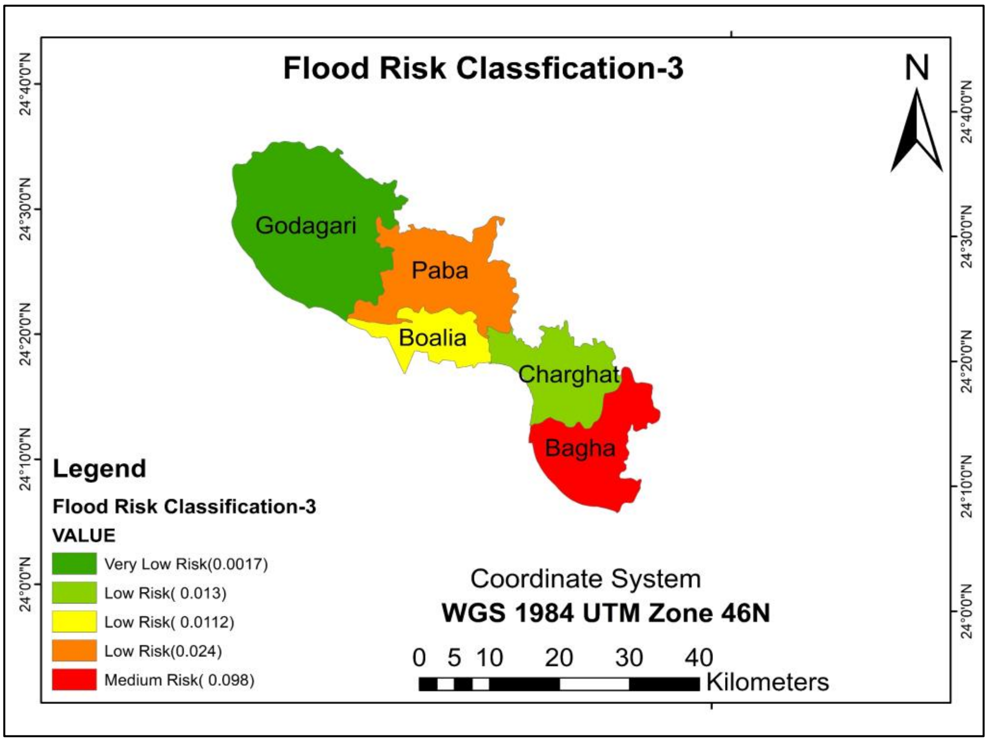

Figure 10c. Flood Risk Classification-3

Conclusion

This study illustrates how effectively geospatial analytics and multi-capital vulnerability analysis were applied to assess and mitigate flood risks in the five upazilas of the Rajshahi district of Bangladesh. Hazard metrics (Highest Flood Level), socio-economic exposure (population density, economic capacity), and physical capital (embankments and flood shelters) were integrated to display stark differences in the spatio-temporal distribution of flood risk. Of these, Bagha stood out as the most vulnerable upazila, rated very high risk on account of higher flood levels with an adaptive capacity less than ideal. Further targeted interventions like the building of flood shelters across 49 sites and 23 km of embankment reduced the flood risk to medium; hence, the strength of infrastructure is crucial for resilience building. Furthermore, Charghat and Paba have been able to significantly improve physical capital such that they have transitioned from medium to low risk. On the other hand, Godagari maintains its very low risk status due to the inherent low hazards, which offset its high vulnerability. The results reiterate that a risk is the product of hazard, exposure, and vulnerability and, hence, must be dealt with in context-specific ways. Hence, this capital-based approach validated through GIS provides a scalable model for prioritizing resource allocation in flood-prone riverine areas. The need for policymakers is to adopt such a composite framework to reduce socio-economic marginalization while bringing about structural measures along with community resilience programs for sustainable disaster mitigation in extremely vulnerable landscapes.

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