

Exploring the Relationship Between Human Vulnerability and Place Risk in Satkhira, Bangladesh

Dr. Bibi Hafsa¹
Shubnam-E-Shubha²
Sifatul Hoque Siam²

Abstract: Climate change poses significant risks to low-lying coastal regions, where environmental hazards interact with socio-economic vulnerability to exacerbate disaster impacts. Bangladesh being one of the world's most environmentally vulnerable deltaic nations is also being threatened by rising levels of global warming and sea-level rise, accompanied by increased events of flood, storm surges, and saltwater intrusion in their raised coastal zones. It is in this light that this research will explore and examine the relationship between the vulnerable nature of humankind and the risk to places in Satkhira, which is one of the highly vulnerable upazilas in south-western Bangladesh. Secondary data sources include the National Climate Vulnerability Assessment, the INFORM Risk Index, and the Bangladesh Bureau of Statistics (BBS). Human Vulnerability Index (HVI) and Place Risk Index (PRI) were developed using the Weighted Linear Combination Method. Pearson's correlation test was used to examine the relationship between HVI and PRI. The findings indicate strong disparities in space within Satkhira District, with the upazilas along the coast, particularly Shyamnagar and Assasuni, being identified as important hotspots where vulnerability factors are linked with high climate-related risk. The overlay test clearly shows the importance of the space along the coast, with increasing risk towards the southern coastal zone. Statistical test outcomes support the presence of extremely strong and positive correlations between vulnerability and geographical location-based risk factors ($r=0.973$, $p=0.05$). The results emphasize the need to have a comprehensive, location-based adaptation and disaster risk reduction strategy targeting both environmental risks and underlying socio-economic vulnerability.

Keywords: Hazard, Vulnerability, Risk, Resilience, Exposure

Introduction

Climate change has become one of the most burning issues of humanity in the twenty-first century with extensive consequences on the ecosystem, economies, and societies all over the world (Shivanna, 2022). The low-lying deltaic areas have a high vulnerability to changes in climate and environmental shocks, which are probably experienced as cyclones, floods, and salinity intrusion, and interact with susceptible and vulnerable socio-economic conditions (Overeem & Syvitski, 2009). Bangladesh is well known as one of the most climate-sensitive countries in the world because it is also one of the largest deltaic countries

¹ Associate Professor, Department of Geography and Environment, Jahangirnagar University, Savar, Dhaka
Email: hafsa@juniv.edu

² Research Student, Department of Geography and Environment, Jahangirnagar University, Savar, Dhaka

in the world and is severely exposed to both slow-onset climate change and extreme weather effects (Huq, 2001; Masum, 2019). Tropical cyclones, coastal flooding, riverbank erosion, and sea-level rise are regular occurrences in the country and they threaten millions of livelihoods (Afjal Hossain et al., 2012). The World Bank estimates that over 13.3 million persons in Bangladesh could be affected due to climate-related effects by 2050, assuming that the current trends persist and that coastal districts would be impacted more (The World Bank Group, 2022).

Satkhira district is in the southwestern coastal part of Bangladesh with the visible effects of a definite set of climate vulnerabilities. Being close to the Bay of Bengal and situated on the Ganges-Brahmaputra-Meghna delta, this place is regularly exposed to multiple hazards, especially cyclones, tidal floods, salinity intrusion, and waterlogging (Golam Rabbani et al., 2022). In Bangladesh, river morphology significantly influences the relationship between a place's vulnerability and risk (Hafsa et al., 2025).

Cyclones like Sidr (2007), Aila (2009), and Amphan (2020) have caused extensive damage to housing, infrastructure, and agricultural lands in the district (Haque & Jahan, 2016; Rashid et al., 2023; Subhani & Ahmad, 2019). Data from the Bangladesh Meteorological Department show a 15% growth in the incidence of tropical cyclones and heatwaves in the Bay of Bengal during the past thirty years (IPCC, 2023). The rate of salinization of freshwater sources and fertile lands due to sea-level rise has been estimated to be around 3.4 mm every year (IPCC, 2023). This threatens food and livelihood security in the area.

Although the physical risks of climate hazards are well-documented in Satkhira, human vulnerability, which can be characterized in terms of socio-economic conditions, population density, education and health varies significantly in the district (Aktar et al., 2024). More than 45 percent of the rural population in Satkhira live below the poverty line and most of the households are dependent on climate sensitive sectors like agriculture and aquaculture (BBS, 2022). That social-economic susceptibility increases climate risks, making matters of climate events human disasters (Birkmann et al., 2015). Vulnerability is ecological and social; it captures the extent to which people are in a position to foresee and manage as well as recuperate from the impacts of climate-related shocks (Otto et al., 2017). Climate adaptation and disaster risk reduction require one to know how human vulnerability is related to the local risk (Lei et al., 2014).

The recent developments in Geographic Information Systems (GIS) and spatial models can offer strong instruments to examine the interaction between physical hazards and human weakness (Tsatsaris et al., 2021). Researchers can map and quantify the intersection of people's vulnerability and hazard exposure by overlapping data sets like the National Climate Vulnerability Assessment (NCVA) and the INFORM Risk Index (Painter et al., 2024; Tedesco et al., 2023). The approaches provide a strong scientific foundation to risk pattern insight and are useful in the design of stated, data-driven policies to aid in sustainable adaptation.

The study is based on spatial research employing a GIS and statistical relationships, asking how human vulnerability can be linked to place-based risk in Satkhira District, Bangladesh. The objective is to identify the areas in which socio-economic fragility is a contributive or matching factor with high environmental exposure and to compare different regions to

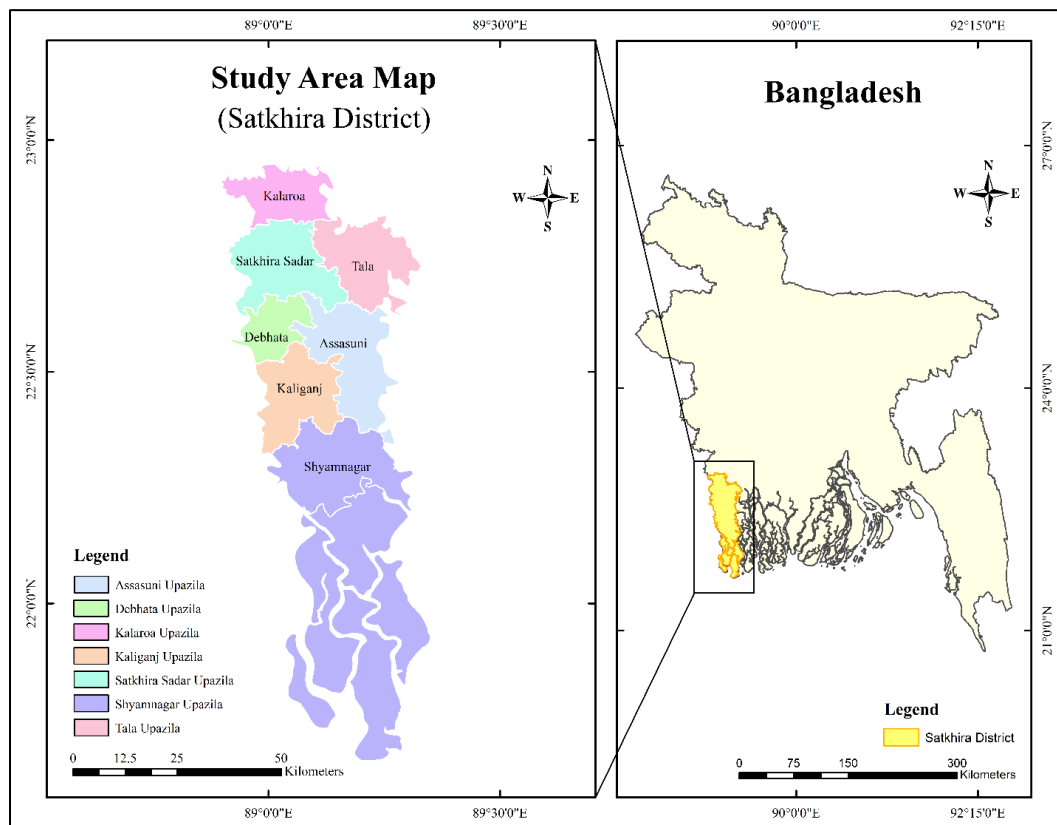
identify patterns where human vulnerability is strongly correlated with heightened place risks. The findings will assist the policymakers and practitioners in focusing their intervention priorities, spending their generated funds in an effective way and coming up with local resolutions and adverse effects of coastal Bangladesh.

Materials and Methods

Study Area

This present study picked Satkhira District, which is situated in the southwest of Bangladesh, having latitudes of $21^{\circ}36' N$ to $22^{\circ}54' N$ and longitudes of $88^{\circ}54' E$ to $89^{\circ}20' E$. The district, which covers about 3,858 square kilometers, is a mixture of terrestrial and coastal landforms with some in the Sundarbans Reserve Forest a UNESCO World Heritage Site (Sarker et al., 2016; Ullah & Rahman, 2015). This forest is very important with regard to protection as it acts as a natural defense against cyclonic movement and tidal waves. The research area is shown in Figure 1 below.

Figure 1: Study Area Map



Source: Completed by the authors (2025)

Satkhira is situated in a tropical monsoon zone in which the winter temperature is close to $12^{\circ}C$ in January, but in May it rises up to approximately $35^{\circ}C$. It receives an average of

1,700 to 2,000 mm of precipitation every year (Ministry of Food and Disaster Management Bangladesh, 2020). Through the past three decades, the temperature of the coasts near Satkhira has gone up by over 1.20°C alongside a 15 percent augmentation in the quantity of intense Bay of Bengal cyclones (Categories 4 and 5) in the area (Prodhan et al., 2025). The Population and Housing Survey reports on the residents of Satkhira, where there are approximately 2.2 million people with a population density of approximately 570 people per square kilometer, with over three-quarters of the population living in the rural areas (BBS, 2022). The literacy level in the district is estimated at 66%, which is below the national average, and more than 45 percent of the residents in the coastal and low-lying areas have incomes below the poverty line (BBS, 2022). The coast is susceptible to rises in sea level, riverbank erosion, cyclonic and salinity intrusion, hence declaring Satkhira as one of the most climate-sensitive districts in Bangladesh.

Methodology

The study adopts a quantitative, spatial, and correlation research design incorporates Geographic Information System (GIS) approaches and statistical analysis for examining the association between human vulnerability and place-based risks in Satkhira District, Bangladesh. The research mostly uses secondary data from reliable national and international sources. The selection of the secondary data was based on the data's appropriateness for the study of the environment and climate vulnerabilities in the context of the country of Bangladesh. A table highlighting the details of the data and the study's objectives can be seen in Table 1 below.

Table 1: Data Sources and Description

Data Type	Data Source	Year	Purpose / Description
Climate and Hazard Data	National Climate Vulnerability Assessment (NCVA), Ministry of Environment, Forest and Climate Change (MoEFCC)	2022	Offers indicators regarding hazard exposure, climate risk zones, and adaptive capacity
Human Vulnerability Indicators	INFORM Risk Index (UNDRR & EU)	2023	Includes multi-dimensional vulnerability data
Demographic and Socio-Economic Data	Bangladesh Bureau of Statistics (BBS)	2022	Provides population, literacy, poverty, and livelihood data
Administrative Boundary Shapefiles	Bangladesh GIS Data Portal / LGED	2022	Used to delineate upazila-level boundaries

Source: Completed by the authors (2025)

The methodological framework (figure-2) combines both secondary data analysis with spatial modeling capability to visualize and measure socio-environmental interactions.

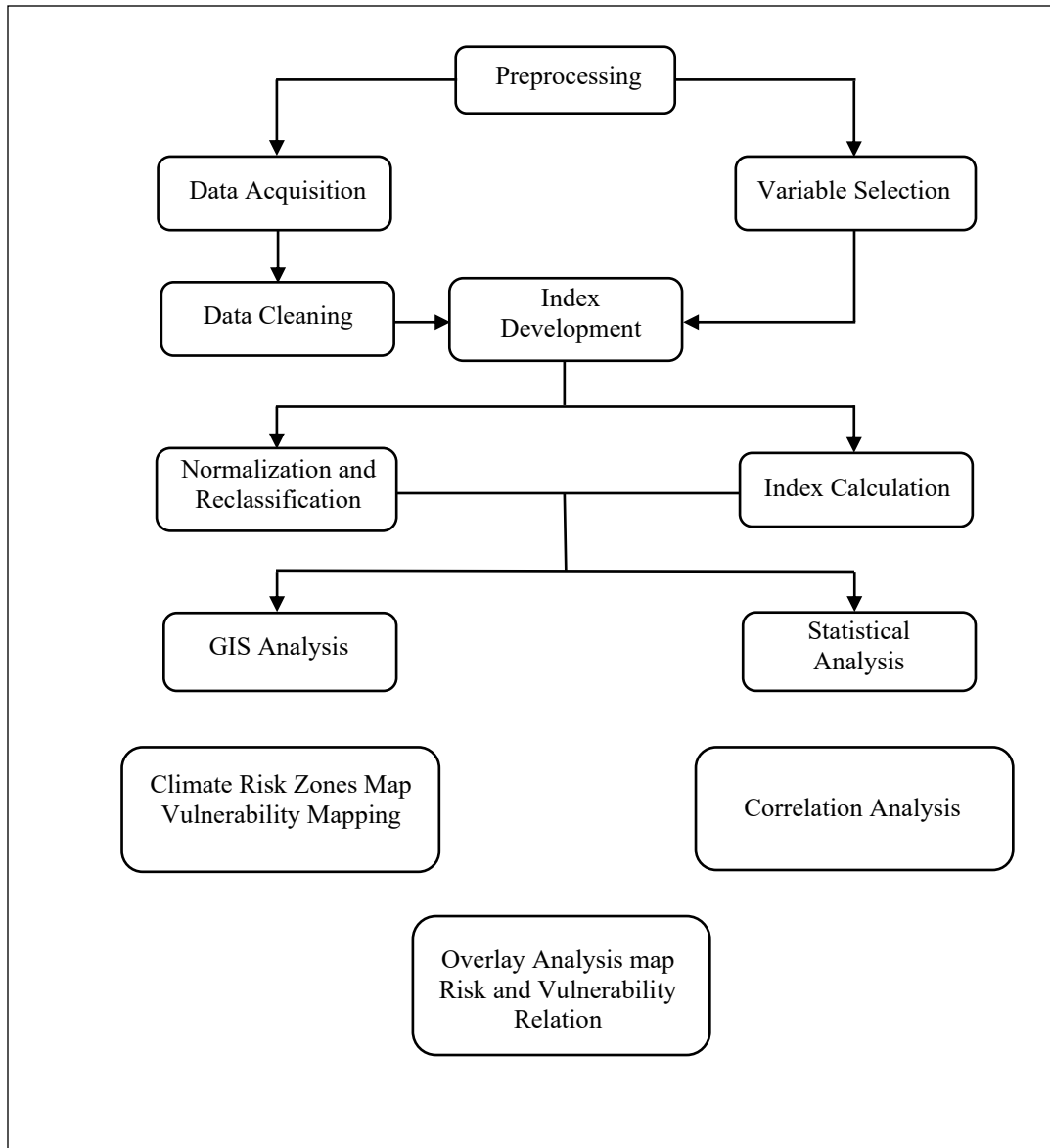


Figure 2: Methodological Framework

Source: Completed by the authors (2025)

Variable Selection

Indicators were categorized into two broad categories: human vulnerability and place-based risk. The choice of features was based on their significance to socio-environmental studies and availability of standardized data. Variables selected for analysis is given in table-2.

Table 2: Selected Variables for Analysis

Category	Variable	Indicator Type	Data Source
Human Vulnerability	Poverty rate (%)	Socio-economic	BBS
	Literacy rate (%)	Educational	BBS
	Health facility density	Infrastructural	INFORM
	Population density	Demographic	BBS
	Access to safe water (%)	Environmental	NCVA
Place-Based Risk	Flood risk index	Environmental	NCVA
	Cyclone exposure index	Climatic	INFORM
	Salinity intrusion area	Environmental	NCVA
	Heat stress index	Climatic	INFORM
	Distance from coast (km)	Spatial	GIS-derived

Source: Completed by the authors (2025)

Data Processing and Standardization

All data sets were re-projected onto a common spatial reference system (WGS 84, UTM Zone 45N). Minimum to maximum scaling was performed to standardize all quantitative variables before analyzing the data, which helped to make the indicators obtained due to the use of various scales comparable to each other (Kappal, 2019). The formula used for normalization was:

$$X = \frac{X' - X_{min}}{X_{max} - X_{min}}$$

Spatial layers were clipped to the Satkhira District administrative boundary, and attribute tables were modified to ensure proper integration in GIS.

GIS Spatial Analysis

Spatial GIS analysis for this study was performed with ArcGIS 10.8 which integrated multi-source datasets to examine and visualize spatial distribution patterns of human vulnerability and place-based risk at Satkhira District. Each indicator was standardized through a min-max normalization technique, and subsequently reclassified into three categories of Low, Moderate and High using the Natural Breaks (Jenks) method (Chen et al., 2013). A Weighted Linear Combination (WLC) method was used to generate the Human Vulnerability Index (HVI) and Place Risk Index (PRI) (Malczewski, 2000). Composite indices were examined with Zonal Statistics at the upazila level to determine mean vulnerability and risk score, categorized into spatial categories, and visualized using color-graded maps. Final outputs of HVI and PRI maps demonstrated spatial distribution patterns of vulnerability hotspots in Satkhira District, and these outputs were validated with secondary data from the National Climate Vulnerability Assessment (2022). Table 3 illustrates the weight distribution for the respective variable used in the GIS overlay process, reflecting the relative contribution of socio-economic and environmental factors to vulnerability and risk intensity throughout Satkhira District.

Table 3: Weight assignment of selected socio-economic and environmental indicators used in the GIS-based overlay analysis.

Indicator	Weight (%)	Rationale
Poverty rate	25	Strong determinant of vulnerability
Literacy rate	10	Reflects awareness and adaptive capacity
Population density	15	Represents exposure pressure
Health facility access	10	Indicates coping capacity
Flood and cyclone risk	20	Key physical hazard factors
Salinity intrusion	10	Major environmental stressor
Heat stress	5	Urban-related hazard
Distance from coast	5	Exposure gradient factor

Source: Developed from NCVA (2022)

Statistical Correlation Analysis

To assess the relationship between human vulnerability and place-based risk, a Pearson's correlation coefficient (r) was computed in R Studio (Oliveira et al., 2020). The following formula:

$$r = \frac{\sum(X - \bar{X})(Y - \bar{Y})}{\sqrt{\sum(X - \bar{X})^2 \sum(Y - \bar{Y})^2}}$$

Where,

X = Human Vulnerability Index

Y = Place Risk Index (PRI)

r = Correlation Value

This method is chosen because it measures the linear relationship between two continuous variables, providing a numerical value that ranges from -1 to +1 (Okoye & Hosseini, 2024).

- A value of +1 or close to +1 indicates positive linear correlation.
- A value of -1 or close to -1 indicates negative linear correlation.
- A value of 0 indicates no correlation

Results and Discussion

The findings of the research shows both the spatial and statistical assessment to examine the interrelationship between human vulnerability and place-based risk across Satkhira District. Through GIS-based modeling and correlation analysis, it shows significant spatial patterns of vulnerability and environmental exposure, very different across the seven upazilas. GIS composite maps of the Human Vulnerability Index (HVI) and Place Risk Index (PRI) show the highest combined levels of vulnerability and risk along the southern coastal belt with high rates of poverty, substandard infrastructure, low levels of literacy, and repeated exposure to cyclones, floods, salinity intrusion, etc.

Spatial Distribution of Climate Risk Zones

In addition to the GIS analysis for spatial distribution of climate risk zones, the 2023 INFORM (Index for Risk Management) data were examined to obtain standardized risk scores for each upazila of Satkhira. The INFORM index utilizes Natural Hazard, Vulnerability and Lack of Coping Capacity to inform a combined risk profile, providing an inclusive view of disaster risks at the local scale. Explanation of INFORM Risk Data is given below:

- INFORM natural hazard represents each upazila's exposure to physical hazards such as floods, cyclones, and salinity intrusion.
- INFORM vulnerability reflects socio-economic fragility, including poverty levels, population pressure, and dependency on natural resources.
- INFORM lack of coping capacity evaluates institutional readiness, infrastructure, and the community's ability to manage and recover from disasters.
- INFORM risk identify the composite score combining the above three dimensions to represent overall disaster risk intensity.

Table 4: INFORM Risk Data for Satkhira Upazilas (2023)

Upazila	Inform natural hazard	Inform vulnerability	Inform lack of coping capacity	Inform risk
Assasuni	6.3	6.9	5.2	6.1
Debhata	6.3	6.7	4.9	5.9
Kalaroa	6.0	6.5	4.8	5.8
Kaliganj	6.5	6.9	5.1	6.1
Satkhira Sadar	6.4	7.0	5.1	6.1
Shyamnagar	5.8	6.9	5.4	6.1
Tala	6.0	7.0	5.0	6.0

Source: INFORM Index, 2023.

As shown in Table 4, INFORM Risk scores for Satkhira's seven upazilas vary between 5.8 and 6.1, thereby showing a low moderate to highly moderate level of risk overall. The top-risk upazilas with respect to overall risk scores (6.1), particularly with moderate vulnerability and low coping capacity despite minor differences in vulnerability and hazard exposure, are Assasuni, Kaliganj, Satkhira Sadar, and Shyamnagar. Additionally, it is shown that for Shyamnagar, there is a high level of vulnerability (6.9), and lack of coping capacity is highest (5.4), thereby signifying that it is highly sensitive to climate risks.

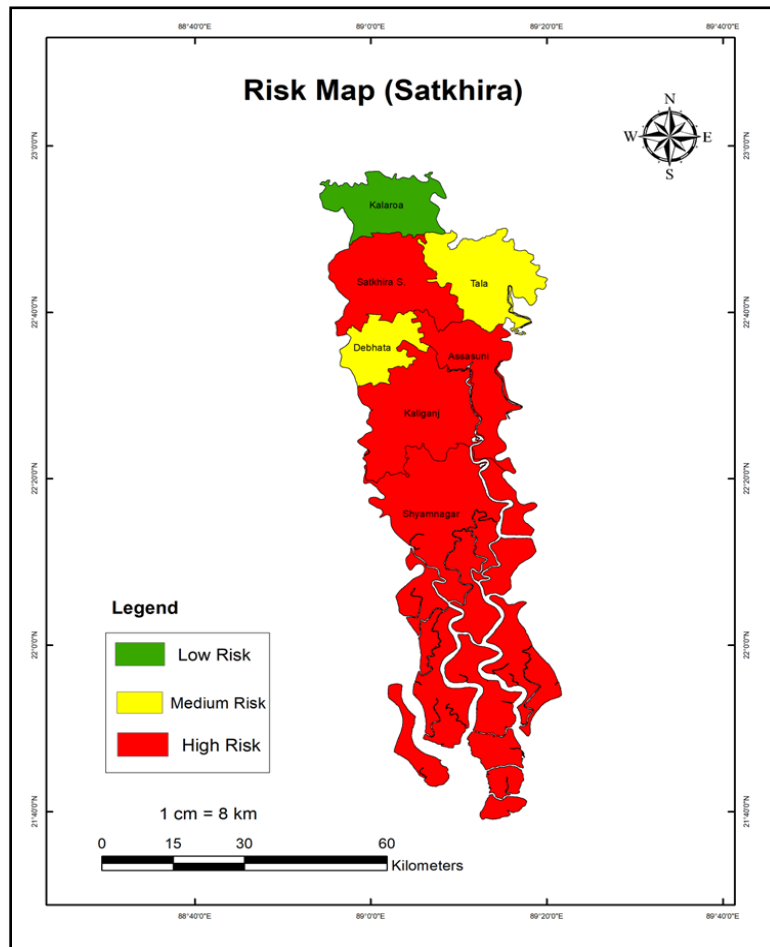
Figure 3 above shows the spatial distribution of the different levels of the climate risk zones in the Satkhira District, with the prominent climate risk zones superimposed on the map. This distribution seems to result in a dominance of the high-risk zones mainly in the southern, south-western coastal regions, including the Shyamnagar and Assasuni upazilas, where the factors are proximity to the Bay of Bengal, topography, frequent cyclonic storm surge occurrences, and the high level of salinity intrusion. Other areas, which are relatively

inland, such as the Kalaroa and Tala upazilas, have a slight lower level of risk.

The geographic pattern in Figure 3 above indicates a clear coast-inland risk gradient with increased risks as one moves closer to the coast. The distinction in risks between the coast and inland areas illustrates well how geographic location affects risks while emphasizing vulnerability in shaping risks. The combination of risk scores with geographic location through GIS mapping therefore helps to demonstrate risks in a clear way in Satkhira District.

In general, the geographic distribution of climate risk zones shows that disaster risk in Satkhira is not equal in every place but rather concentrates in certain spots because the coastal upazilas are exposed to cumulative risks from high levels of exposure to hazards, sensitivity to disaster impacts, and lack of disaster risk management capacity at the same time. This geographic information plays an important role in determining disaster risk management target zones in the next stage.

Figure 3: Major climate risk Zone in Satkhira District.



Source: Completed by the authors from INFORM Risk Data (2025)

Human Vulnerability Mapping

The Human Vulnerability Index (HVI) was calculated using the variables of poverty rates, literacy rates, population density, health infrastructure, and access to safe water. There is large variation within the districts. Vulnerability index of human vulnerability, classified at the upazilla level, is shown in Table 5.

Table 5: Human Vulnerability Index (HVI) by Upazila

Upazila	Poverty (%)	Literacy (%)	Health Facility Density (per 10,000)	HVI Value	Vulnerability Level
Shyamnagar	52.3	57.8	0.6	0.82	High
Assasuni	49.7	59.2	0.7	0.78	High
Kaliganj	43.1	64.3	0.8	0.65	High
Debhata	38.9	66.1	1.1	0.59	Medium
Satkhira Sadar	33.2	70.5	1.5	0.55	Medium
Kalaroa	36.5	68.2	1.3	0.53	Medium
Tala	30.8	72.4	1.6	0.42	Low

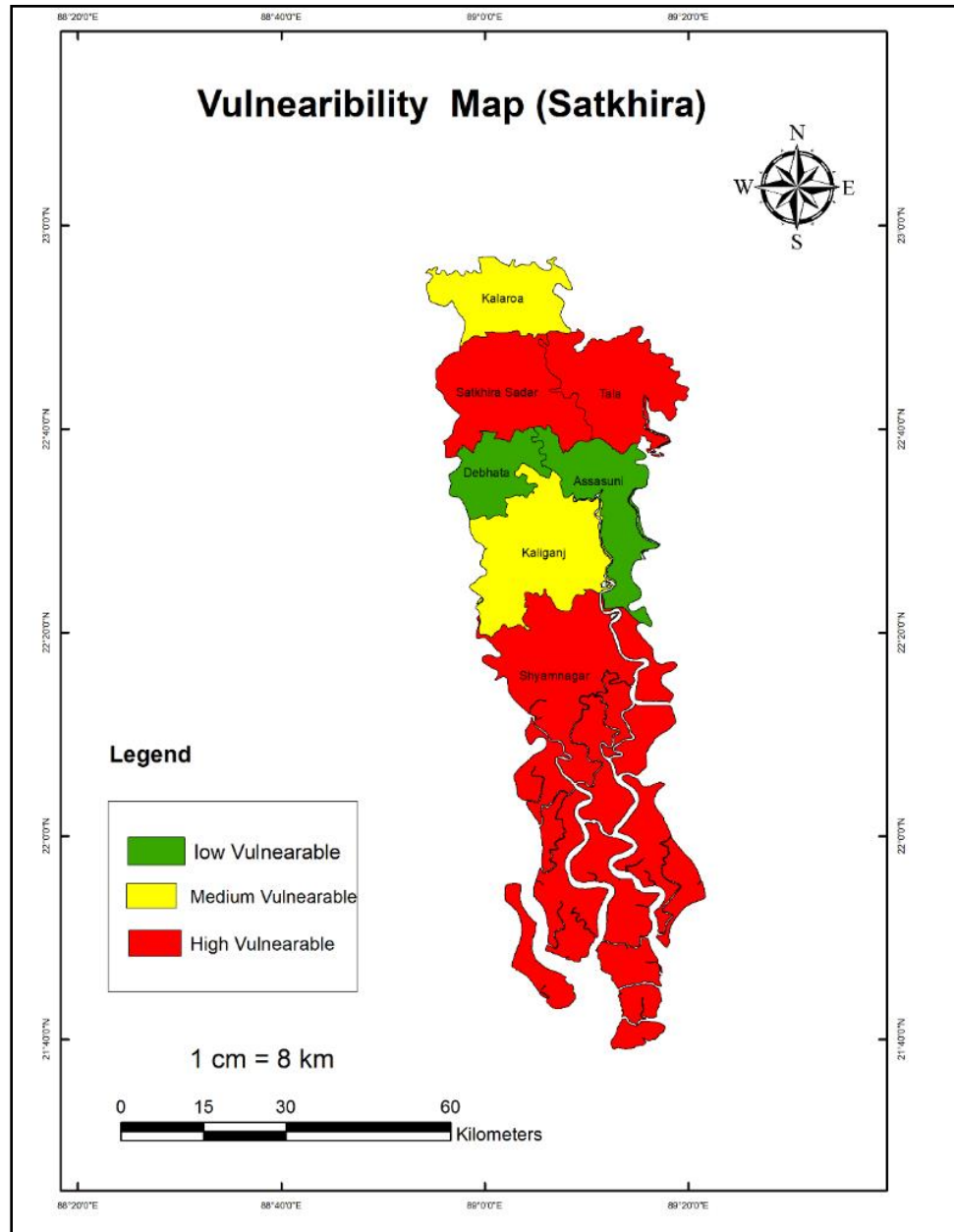
Source: Calculated from BBS (2022), INFORM (2023), and NCVA (2022).

Vulnerability zones are an expression of the socio-economic elements which can worsen the effect of climate risks. These are:

- **Poverty Zones:** Locations with the highest rates of poverty were regarded as extremely vulnerable to climate-related threats.
- **Population Density Zones:** These are areas that are more densely populated and thus remain at risk because of their infrastructure constraints and sensitivity.
- **Access to Healthcare and Education:** Regions that have limited access to healthcare services and education will be classified as vulnerable, since this will impede the ability of those people to adapt to the effects of climate change.

The spatial pattern (Figure- 4) clearly expounds Shyamnagar and Assasuni to have a greater level of vulnerability in view of their poor socio-economic conditions. Moreover, their less educated population and lack of access to proper facilities have been identified to have higher levels of vulnerability. At the opposite end are Tala and Kalaroa with lower levels of vulnerability.

Figure 4: Human Vulnerability across Satkhira District.



Source: Completed by the authors from Human Vulnerability Index (2025)

Comparative Spatial Analysis of Upazilas

The combined analysis of HVI and PRI allowed the classification of each upazila into distinct risk–vulnerability categories, summarized below.

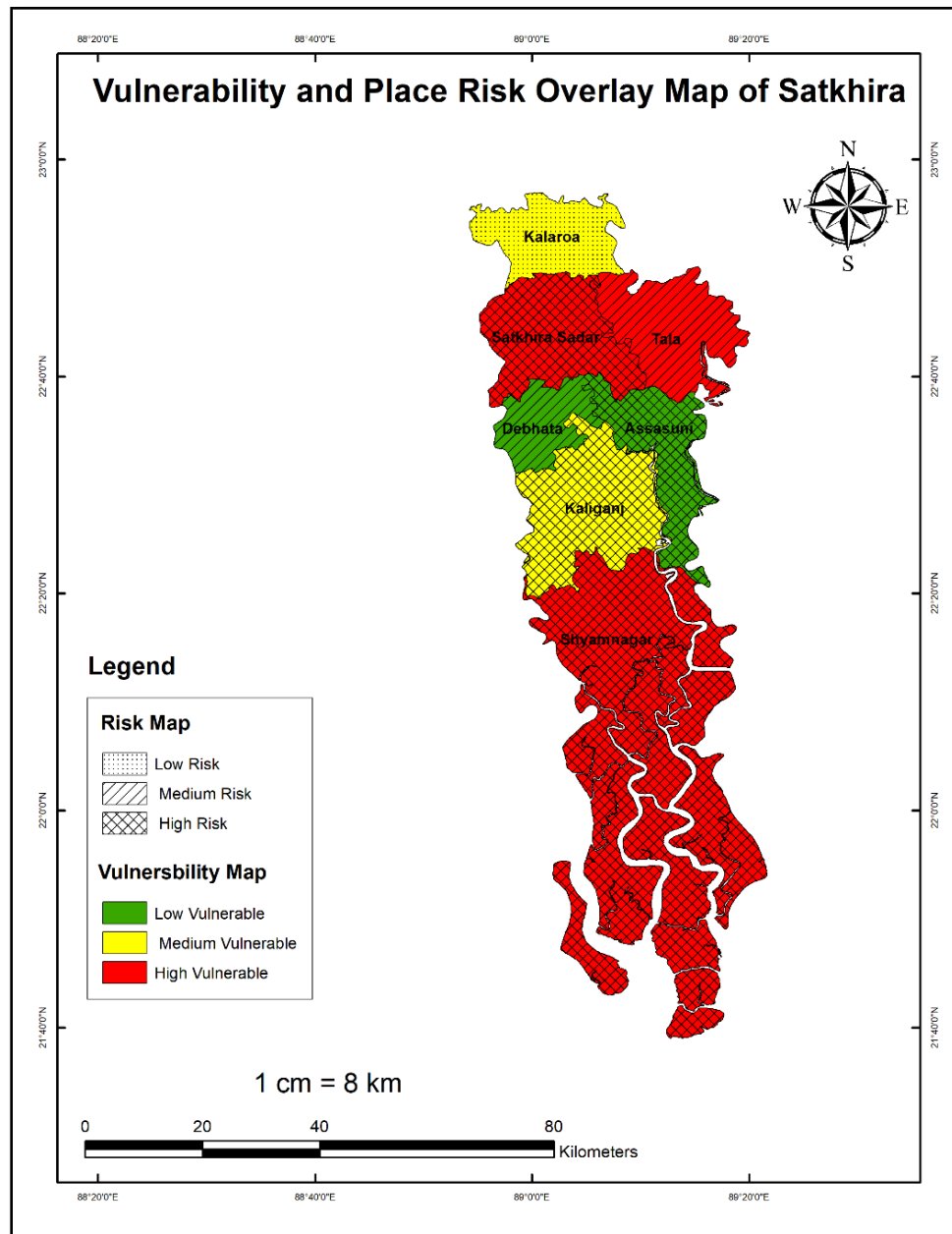
Table 6: Comparative Risk–Vulnerability Assessment

Upazila	Human Vulnerability	Place Risk (PRI)	Combined Status	Interpretation
Shyamnagar	Very High	Very High	Critical	Multi-hazard zone; extreme poverty and salinity intrusion
Assasuni	Very High	Very High	Critical	High exposure to cyclone and flood events
Kaliganj	High	High	Severe	Agricultural dependency; moderate resilience
Satkhira Sadar	Moderate	Moderate	Moderate	Urban exposure to heat stress; better healthcare
Debhata	Moderate	Moderate	Moderate	Moderate flood and salinity risk
Kalaroa	Moderate	Moderate	Moderate	Balanced socio-economic profile
Tala	Low	Low	Low	Lowest overall risk; relatively resilient area

Source: Completed by the authors (2025)

Spatially, the vulnerable upazilas in the south (Shyamnagar & Assasuni) are the most vulnerable hotspots, whereas Tala is identified to be relatively safe zones because of better infrastructure development and less exposure to hazards. The upazilas in the central region like Kaliganj and Debhata are transitional regions with moderate levels of vulnerability that might increase in more harsh climate conditions. The overlay outcomes clearly demonstrate how collectively vulnerable areas with high HVI and PRI values are regions having overlapping vulnerable conditions because of both natural and socio-economic factors. These regions are not only vulnerable to frequent cyclonic events, flooding, and saline water intrusion but are also less equipped to adapt to such conditions because of their deprivation in education and healthcare facilities. Overlay map demonstrating combined values for Human Vulnerability and Place-Based Risk in Satkhira District is depicted in Figure 5.

Figure 5: Overlay map of Human Vulnerability and Place-Based Risk in Satkhira.



Source: Completed by the authors from INFORM Risk Data and HVI (2025)

Correlation Between Human Vulnerability and Place-Based Risk

To statistically evaluate the association between socio-economic vulnerability and environmental risk, an analysis of the correlation (Pearson's) was conducted using R studio

on the Human Vulnerability Index (HVI) and Place Risk Index (PRI) at the upazila level. The analysis is shown in figure 6.

Figure 6: Correlation analysis in R studio between Human vulnerability and Place risk.

```
R version 4.4.1 (2024-06-14 ucrt) -- "Race for Your Life"
Copyright (C) 2024 The R Foundation for Statistical Computing
Platform: x86_64-w64-mingw32/x64

R is free software and comes with ABSOLUTELY NO WARRANTY.
You are welcome to redistribute it under certain conditions.
Type 'license()' or 'licence()' for distribution details.

Natural language support but running in an English locale

R is a collaborative project with many contributors.
Type 'contributors()' for more information and
'citation()' on how to cite R or R packages in publications.

Type 'demo()' for some demos, 'help()' for on-line help, or
'help.start()' for an HTML browser interface to help.
Type 'q()' to quit R.

> # Example data for INFORM Risk and Vulnerability Scores
> upazila <- c("Assasuni", "Debhata", "Kalaroa", "Kaliganj", "Satkhira Sadar", "Tala", "Shyamnagar")
> inform_risk <- c(6.1, 5.9, 5.8, 6.0, 0.8351, 1.1084, 6.1) # INFORM Risk Scores
> vulnerability_score <- c(5.2, 6.3, 4.9, 6.5, 0.8351, 1.1084, 6.1) # Vulnerability Scores
>
> # Combine the data into a data frame
> data <- data.frame(upazila, inform_risk, vulnerability_score)
>
> # Calculate the correlation between INFORM Risk and Vulnerability Score
> correlation <- cor(data$inform_risk, data$vulnerability_score)
>
> # Print the correlation result
> print(correlation)
[1] 0.9731775
>
```

Source: Completed by the authors (2025)

Table 7 shows the result of Pearson's correlation result:

Table 7: Correlation Analysis Result

Variables	Correlation Coefficient (r)	Significance (p-value)	Relationship
HVI vs PRI	0.973	< 0.05	Strong Positive

Source: Completed by the authors (2025)

The result showed that there is a strong positive correlation between the variables ($r = 0.973$, $p < 0.05$), which indicates that the areas with more vulnerability to the socioeconomic dimensions, are also the ones with more vulnerability to the environmental dimensions. The near-perfect result clearly indicates that the two dimensions are interlinked in such a way that the areas with less accessibility to education, healthcare, and

economic accessibility, are also the ones with more vulnerability to natural disaster risks such as flood, cyclone, salinity, etc. The strong positive result clearly supports the fact that the hotspots for vulnerability are collocated in Satkhira, along with the hotspots of risk. Reducing the climate risk in Satkhira requires targeting the source of the problem the socio-economic issue, together with the hazard.

Discussion

The geographical distribution of zones of climate risk shows a strong coastline to inland vulnerability gradient with intensified risk values in Shyamnagar and Assasuni. The results reveal that Bangladesh's south-western coastal region is a climate hotspot due to its topographic vulnerability to storm surges driven by cyclones in the Bay of Bengal. The HVI mapping analysis indicates a strong vulnerable variability of socio-economic conditions in Shyamnagar, Assasuni, and Kaliganj with a high vulnerability index. Poverty rates, illiteracy, lack of access to health care, and vulnerability to climate-sensitive sectors such as agriculture or fish farming have contributed to a high vulnerability index in those areas.

The combined risk-vulnerability comparison further clarifies the spatial alignment between HVI and PRI. Critical and severe classes of upazilas fall predominantly along the southern coastal belt where environmental hazards intersect with socioeconomic fragility. The overlay analysis also visually confirms that areas of high vulnerability essentially coincide with areas of high place-based risk. This spatial pattern is strongly supported by the quantitative results of the statistical correlation analysis. The very strong and statistically significant positive correlation between HVI and PRI ($r = 0.973$, $p < 0.05$) infers that socio-economic vulnerability and place-based climate risk are strongly interlinked in Satkhira District. This near-perfect correlation suggests that improvement in socio-economic conditions-poverty reduction, increased education, and strong health infrastructure- can eventually reduce overall climate risk by a large margin. Comparable relations of vulnerability with risk have been measured in other coastal and delta regions where people in backward classes suffer more from climate change hazards due to their limited adaptive capacity.

Conclusion

The research explored the spatial relationship between human vulnerability and place risk in the Satkhira District of Bangladesh through a combined GIS and statistical analysis. In order to achieve this, a Human Vulnerability Index (HVI) and a Place Risk Index (PRI) have been derived, and through these indexes, a comprehensive analysis of the relationship of human and physical risk in the specified area of the highly climate-sensitive region of the coastal zone of Bangladesh has been provided. The Southern upazilas, mainly Shyamnagar and Assasuni, were chosen for being hotspot areas that together experience maximum vulnerability to cyclones, floods, saline intrusion, and waterlogging, along with highly threatening factors such as high poverty, poor access to health and educational facilities, and high sensitivity to disasters for their business-related activities. On the other hand, upazilas like Tala, Kalaroa, have been observed to experience low vulnerability or risk, mainly because they have better socio-economic conditions, along with low

vulnerability to disasters like cyclones. The result of the risk-vulnerability overlay analysis using both hazard and vulnerability data provides insight that the risk is not uniformly distributed and is, in fact, geographically concentrated, with an obvious gradient from the coastline to the interior. The statistical test above confirms and supports this, and the result is highly significant and of great value, indicating an obvious, strong, and direct positive relationship between HVI and PRI ($r = 0.973$, $p < 0.05$). This research provides a transferable approach to climate-related hotspot identification and can act as a model study to guide targeted policy action in regions with comparable climate-related threats.

References

- Afjal Hossain, Md., Imran Reza, Md., Rahman, S., & Kayes, I. (2012). *Climate Change and its Impacts on the Livelihoods of the Vulnerable People in the Southwestern Coastal Zone in Bangladesh* (pp. 237–259). https://doi.org/10.1007/978-3-642-22266-5_15
- Aktar, S. , Tauhid Hossain, M. , Sheikh, N. , Redwan, F. , Masum Billah, M. , Sheikh, S. , Habibur Rahman, M. , Nahar, K. , Siddiqua, A. , & Nusrat Binte Nur, M. (2024). Risk Perceptions and Vulnerability Assessment: Induced from Tropical Cyclone in the Southern Part of Coastal Bangladesh. *Journal of Agroforestry and Environment*.
- BBS. (2022). *POPULATION & HOUSING CENSUS 2022*.
- Birkmann, J., Cutter, S. L., Rothman, D. S., Welle, T., Garschagen, M., van Ruijven, B., O'Neill, B., Preston, B. L., Kienberger, S., Cardona, O. D., Siagian, T., Hidayati, D., Setiadi, N., Binder, C. R., Hughes, B., & Pulwarty, R. (2015). Scenarios for vulnerability: opportunities and constraints in the context of climate change and disaster risk. *Climatic Change*, 133(1), 53–68. <https://doi.org/10.1007/s10584-013-0913-2>
- Chen, J., Yang, S. T., Li, H. W., Zhang, B., & Lv, J. R. (2013). Research on Geographical Environment Unit Division Based on the Method of Natural Breaks (Jenks). *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XL-4/W3, 47–50. <https://doi.org/10.5194/isprsarchives-XL-4-W3-47-2013>
- Golam Rabbani, Md., Nasir Uddin, Md., & Munira, S. (2022). Changing Climatic Hazards in the Coast: Risks and Impacts on Satkhira, One of the Most Vulnerable Districts in Bangladesh. In *Climate Change in Asia and Africa - Examining the Biophysical and Social Consequences, and Society's Responses*. IntechOpen. <https://doi.org/10.5772/intechopen.98623>
- Hafsa, B., Siam, S. H., Reza, M., Hossen, S. M. S., Swadhin, A. S. M. Z., Akash, K. M. A. I., Ali, K. S., & Mahmud, K. H. (2025). Geomorphometric Insights into the Dharla and Teesta River Basins through GIS and RS Methods. *Journal of Business and Social Sciences*, 2025(3). <https://doi.org/10.61453/jobss.v2025no40>

- Haque, A., & Jahan, S. (2016). Regional Impact of Cyclone Sidr in Bangladesh: A Multi-Sector Analysis. *International Journal of Disaster Risk Science*, 7(3), 312–327. <https://doi.org/10.1007/s13753-016-0100-y>
- Huq, S. (2001). Climate Change and Bangladesh. *Science*, 294(5547), 1617–1617. <https://doi.org/10.1126/science.294.5547.1617>
- IPCC. (2023). *Climate Change 2021 – The Physical Science Basis* (Intergovernmental Panel on Climate Change, Ed.). Cambridge University Press. <https://doi.org/10.1017/9781009157896>
- Kappal, S. (2019). *Data Normalization using Median & Median Absolute Deviation (MMAD) based Z-Score for Robust Predictions vs. Min-Max Normalization*.
- Lei, Y., Wang, J., Yue, Y., Zhou, H., & Yin, W. (2014). Rethinking the relationships of vulnerability, resilience, and adaptation from a disaster risk perspective. *Natural Hazards*, 70(1), 609–627. <https://doi.org/10.1007/s11069-013-0831-7>
- Malczewski, J. (2000). On the Use of Weighted Linear Combination Method in GIS: Common and Best Practice Approaches. *Transactions in GIS*, 4(1), 5–22. <https://doi.org/10.1111/1467-9671.00035>
- Masum, J. H. (2019). *Climatic Hazards in Bangladesh: A Literature Review*. https://www.researchgate.net/profile/Syed-Masum/2/publication/355202936_Climatic_Hazards_in_BangladeshA_Literature_Review/links/6167e80525be2600ace596f2/Climatic-Hazards-in-Bangladesh-A-Literature-Review.pdf
- Ministry of Food and Disaster Management Bangladesh. (2020). *Impact Assessment of Climate Change and Sea Level Rise on Monsoon Flooding*.
- Okoye, K., & Hosseini, S. (2024). Correlation Tests in R: Pearson Cor, Kendall's Tau, and Spearman's Rho. In *R Programming* (pp. 247–277). Springer Nature Singapore. https://doi.org/10.1007/978-981-97-3385-9_12
- Oliveira, T. P., Moral, R. A., Zocchi, S. S., Demetrio, C. G. B., & Hinde, J. (2020). lcc: an R package to estimate the concordance correlation, Pearson correlation and accuracy over time. *PeerJ*, 8, e9850. <https://doi.org/10.7717/peerj.9850>
- Otto, I. M., Reckien, D., Reyer, C. P. O., Marcus, R., Le Masson, V., Jones, L., Norton, A., & Serdeczny, O. (2017). Social vulnerability to climate change: a review of concepts and evidence. *Regional Environmental Change*, 17(6), 1651–1662. <https://doi.org/10.1007/s10113-017-1105-9>
- Overeem, I., & Syvitski, J. P. M. (2009). *Dynamics and Vulnerability of Delta Systems*. https://www.researchgate.net/profile/Ipo-Future-Earth/Coasts/publication/281241139_RS_35_Dynamics_and_Vulnerability_Of_Delta_Systems/links/55dc8b9508aeb38e8a8d2057/R-S-35-Dynamics-and-Vulnerability-Of-Delta-Systems.pdf

- Painter, M. A., Shah, S. H., Damestait, G. C., Khalid, F., Prudencio, W., Chisty, M. A., Tormos-Aponte, F., & Wilhelmi, O. (2024). A systematic scoping review of the Social Vulnerability Index as applied to natural hazards. *Natural Hazards*, 120(8), 7265–7356. <https://doi.org/10.1007/s11069-023-06378-z>
- Prodhan, Md. M. H., Islam, Md. B., Ashraf, M., & Tarannum, N. (2025). Spatio-temporal patterns and trends of Sunshine duration across Bangladesh during 1985–2022. *Theoretical and Applied Climatology*, 156(5), 284. <https://doi.org/10.1007/s00704-025-05497-w>
- Rashid, M. B., Sheikh, M. R., Haque, A. J. M. E., Patwary, M. A. A., Siddique, M. A. B., Habib, M. A., & Sarker, M. N. (2023). Consequences of catastrophic cyclone Amphan in the human-induced coastal plain ecosystems of Bangladesh. *Case Studies in Chemical and Environmental Engineering*, 8, 100467. <https://doi.org/10.1016/j.cscee.2023.100467>
- Sarker, S. K., Reeve, R., Thompson, J., Paul, N. K., & Matthiopoulos, J. (2016). Are we failing to protect threatened mangroves in the Sundarbans world heritage ecosystem? *Scientific Reports*, 6(1), 21234. <https://doi.org/10.1038/srep21234>
- Shivanna, K. R. (2022). Climate change and its impact on biodiversity and human welfare. *Proceedings of the Indian National Science Academy*, 88(2), 160–171. <https://doi.org/10.1007/s43538-022-00073-6>
- Subhani, R., & Ahmad, M. M. (2019). Socio-Economic Impacts of Cyclone Aila on Migrant and Non-Migrant Households in the Southwestern Coastal Areas of Bangladesh. *Geosciences*, 9(11), 482. <https://doi.org/10.3390/geosciences9110482>
- Tedesco, M., Foster, S., Baptista, A., & Zuzak, C. (2023). A Multi-Hazard Climate, Displacement and Socio-Vulnerability Score for New York City. *Sustainability*, 16(1), 42. <https://doi.org/10.3390/su16010042>
- The World Bank Group. (2022). *Country Climate and Development Report for Bangladesh*. <https://www.worldbank.org/en/news/feature/2022/10/31/key-highlights-country-climate-and-development-report-for-bangladesh>
- Tsatsaris, A., Kalogeropoulos, K., Stathopoulos, N., Louka, P., Tsanakas, K., Tsesmelis, D. E., Krassanakis, V., Petropoulos, G. P., Pappas, V., & Chalkias, C. (2021). Geoinformation Technologies in Support of Environmental Hazards Monitoring under Climate Change: An Extensive Review. *ISPRS International Journal of Geo-Information*, 10(2), 94. <https://doi.org/10.3390/ijgi10020094>
- Ullah, M., & Rahman, M. (2015). Assessing Vulnerability and Adaptation to Climate Change by Farming Communities in Southwestern Coastal Bangladesh. *Journal of Environmental Science and Natural Resources*, 7(2), 31–35. <https://doi.org/10.3329/jesnr.v7i2.22200>