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Investigating the Climate Induced Coastal Vulnerability Index in the Southwest Coastal Region of Bangladesh

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Abstract: The coastal zone of Bangladesh is characterized by developing shallow deltas subject to very high tides and frequent cyclones from the Bay of Bengal. People in Bangladesh's coastal areas are becoming more vulnerable to the threat of climate change, resulting in relatively higher levels of poverty than elsewhere in the country. Potential impacts of sea-level rise in coastal areas include coastal erosion, saltwater intrusion, flooding of wetlands and estuaries, and threats to cultural and historical resources and infrastructure. The main objective of this study is to predict coastal vulnerability in the south-western coastal zone of Bangladesh to assess coastal exposure and vulnerability to natural hazards. Six geophysical and climatic parameters, i.e., variations in elevation, slope, water depth, temperature, precipitation and coastline were considered to simulate the model. All parameters were pre-processed, analyzed, normalized (rescaled) and ranked on a low to high vulnerability range from 1 to 5 to build a Coastal Vulnerability Index (CVI) model. Findings indicate that the north-western part of the study area (Satkhira district) is highly vulnerable to climate change. Densely populated areas are at risk from climate change, with an area of approximately 434.88 square kilometres highly vulnerable to climate change challenges. Most of the region is moderately exposed to natural disasters. This research approach can be applied on a regional scale to other coastal areas to easily identify climate impacts on coastal communities for future development and planning by scientists, researchers and policy makers.

Keywords: Climate Change; Vulnerability; Coastal Zone; GIS; Coastal Vulnerability Index

1. Introduction

Bangladesh is a highly populated nation that deals with a variety of environmental and social issues brought on by environmental degradation, deforestation, poverty, poor governance, and a low degree of industrialisation as well as climate change.[4,5,27] Furthermore, due to its low-lying coastal regions that are frequently exposed to environmental disturbances, the country is one of the most vulnerable to climate change.[1,24,19,25] The coastal zone is densely inhabited in addition to having natural risks that are frequent and of high severity.[20] With an average household size of 5.08 (in the non-coastal zone it is 4.77) and a total of 6,855,555 homes in the coastal zone of Bangladesh. As a result, compared to the rest of Bangladesh, coastal areas are more vulnerable to natural disasters such SLR, storm surges, and cyclones.[25,19,9]

Every year we face various types of disasters on climate change. In Bangladesh, a changing of climate is one of the most common matters. Bangladesh has been affected by repeated and acute climate change impacts on coastal zone in current decades.[3] Shore zones remain considered to be one of the most vulnerable environmental systems to the current and predicted risks associated with climate change.[23] Shore occupies only about 2% of the entire area of the earth, but about 10% of the world's populace living inside 10 meters of sea level.[22] Various coastal regions are threatened by climate change. One of the greatest threats to climate change in these regions is rising sea levels. Around 2.2 billion people, 29% population of the world, lives in an area of flood-prone with different levels of flooding.[26] Rising sea levels lead to seawater invasion and coastal corrosion on land, exacerbating the effects of coastal storms.[31] These regions are sensitive to rise the sea levels, increasing flood levels and rainfall, increasing sea level temperatures, accelerating coastal erosion and seawater invasion, and of population migration, property loss, economic and industrial activity. It has significant socioeconomic effects like decline, reduced coastal derisiveness, tourism, recreation, and loss of transport function.[23] In addition to the swelling stress of climate change, shore areas have been harshly exaggerated by unmaintainable social activity for centuries, resulting in an increasingly lasting threat to coastal ecosystems.[14]

An increasing number of communities are performing vulnerability assessments to learn more about the consequences of natural catastrophes and the adaptability of human and natural systems.[11,16] However, vulnerability has been and is a contentious term due to the sometimes vague and poorly understood interactions between its components and the lack of established techniques for the selection and aggregation of indicators.[16,8] Given that vulnerability is context- and purpose-specific, there is no paradigm for operationalizing vulnerability that is better or worse than others.[10,17] The attempts to map coastal vulnerability, however, appear to still be significantly diverging, with many research continuing to focus on physical hazards and/or biophysical factors.[29,18,7] This is in contrast to the general vulnerability assessment literature, which has converged. This could be the case since the Coastal Vulnerability Index (CVI) is one of the early mapping projects, was fully founded on physical exposure measurements.[12-13]

GIS, a set of software tools designed to gather, save, update, modify, analyse, and present various forms of spatially linked data. Today, GIS is essential for understanding the geographically distribution pattern of ordinary phenomena and climatic factors and for conducting multi-perspective analyses of them. Hence, this study adopted the assessment of Coastal Vulnerability Index considering indicators based on spatial variations in GIS environment.

2. Aim and Objectives of the Study

The study's major aim is to evaluate Bangladesh's southwest coastal regions' vulnerability to the effects of climate change. To achieve the goal, following objectives are adopted:

- To generate the mapping for each vulnerability parameter.
- To calculate the Coastal Vulnerability Index and vulnerability zones in southwest coastal area of Bangladesh.

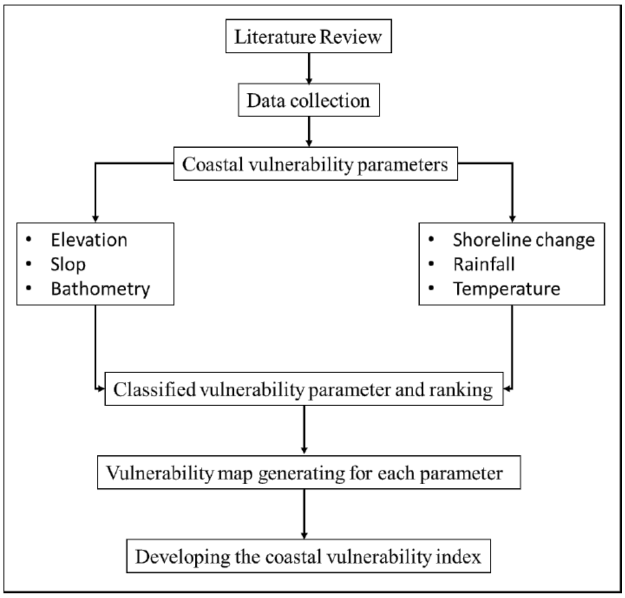

Fig. 1. Framework of the Study.

3. Materials and Method

The study area was selected after the identification of the problem. Later an exploration survey was conducted along the coastal areas, and relevant literature was reviewed. The analysis method was chosen based on information and observation obtained from literature review and investigation survey. Data collection and preparation were done by considering the method of analysis. Steps are shown in Fig. 1.

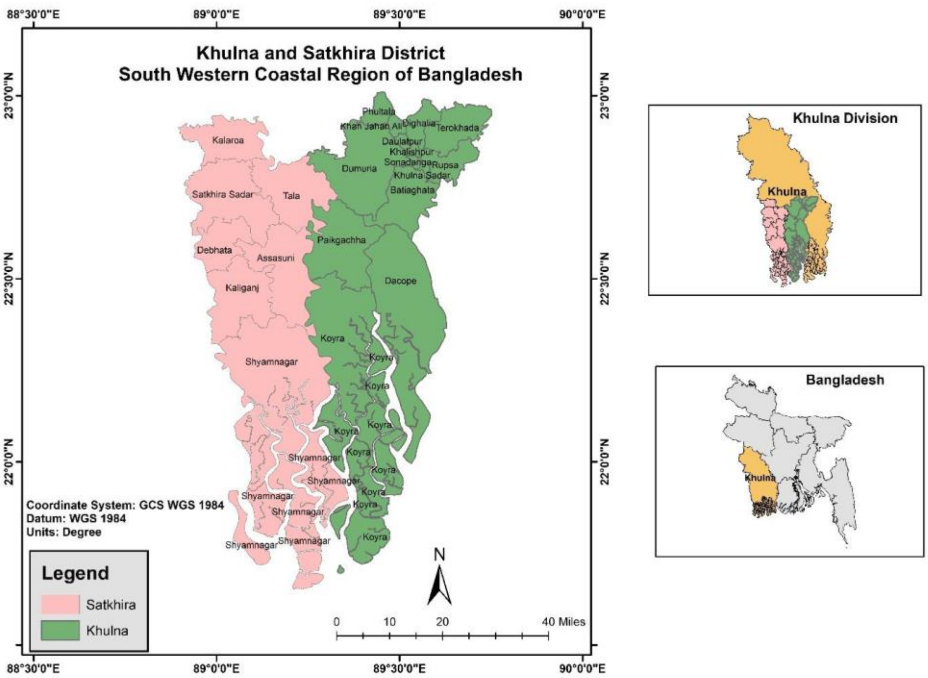

Fig. 2. Khulna and Satkhira District of Southwestern Coastal Region of Bangladesh.

Table 1. List of collected data and information to conduct the study.

Data and Information	Type	Status and time	Data source
Satellite Image	Landsat TM5	2022	
Elevation (DEM)	SRTM DEM (.tif file)	2014, 10 m	
Slope	SRTM DEM	2014, 10m	CEGIS,
Land use	Polygon shape file	2021	Bangladesh
Boundary	Polyline Shape file	2021	
Bathymetry	Elevation point data	2020	
Rainfall	mm/day	1980-2021	Power
Temperature	Daily	1980-2021	NASA

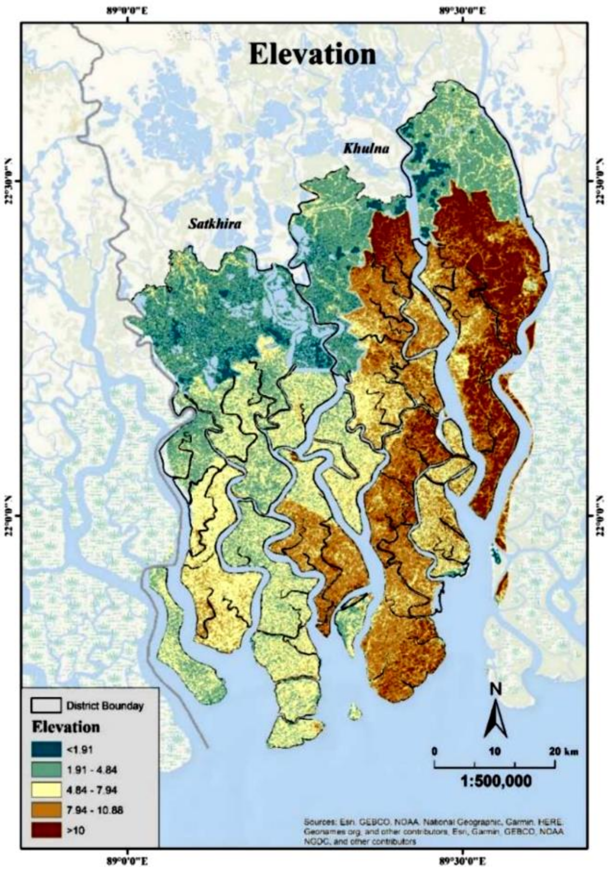

Fig. 3. Elevation of Satkhira and Khulna Coast.

3.1. Study Area

The area is situated in Bangladesh's southwest (Fig. 2) and includes the coastal districts of Khulna and Satkhira. It rains roughly 1500–2000 mm in this area yearly, and about 70% of that rain falls in the form of hail on account of the rainy season. The area is part of the tidal delta, and the floodplain is made up of both active and passive parts of the Ganges delta depositions primarily made up of sand and sand-like silt and clay in the Quaternary period.[30] This area's aquifer system is made up of this rock. Rather to being continuous, these aquifers have intertwined layers of sand, silt, and clay at varied depths 1.5 to 335 ft. The quality of the groundwater is so bad that it's unfit for human consumption. The Saline or brackish aquifers with high chloride concentrations are common, but freshwater aquifers are less common high levels of arsenic.[2]

3.2. Data Collection

The data collection phase of the research is the most crucial and time-consuming. To acquire consistent results, it's also crucial to make sure the data are accurate. Additionally, the data and info for this study were gathered from various trustworthy sources. Most of the data gathered from various secondary sources (Table 1).

3.3. Data processing and analysis

Data that has been gathered from various secondary sources has been processed and brought into compliance with the use of various tools. ArcGIS 10.2, machine learning language, and Microsoft Excel were used to pre-process the majority of the data. Using information from the Landsat-TM 5 satellite and cross-referencing with pictures from Google Earth, a land use land cover map of the study region has been produced. Following a global standard, the quality and amount of each climate variable used to run the model was graded. The population grid map has been created using the population census data set and involves a number of steps. Additionally, the canopy height was ignored after pre-processing the SRTM DEM to fill sink and No Data. Using the Arc GIS program, all the maps have been digitally preserved and plotted.

3.4. Costal Vulnerability Methods

We utilized a standard CVI technique to examine the coastal susceptibility to several hazards in Bangladesh's eastern coastal area.[6,15,17] CVI is the most efficient and simple technique for assessing coastal vulnerability. Six relevant components (Elevation, Coastal slope, Bathymetry, Shoreline Change, Rainfall, and Temperature) with focus largely on natural aspects were chosen and mapped as of multiple data resources using remote sensing along with spatial evaluation procedures. The factors were also integrated and sorted to produce a CVI map.

3.5. CVI calculation

We divided the entire coastline into 470 1 km x 1 km grids and used the coastal position from 2016 to calculate the CVI. Then, each grid received the vulnerability ranks of the six chosen parameter possibilities. Equation (1) was then used to determine the CVI as split by the total number of parameters by the square root of the ranked parameters.[17] Each parameter was given equal weight in the final CVI computation.

$$CVI = \sqrt{(a * b * c * d * e * f * g * h * i)} / 9 \quad (1)$$

Where,

a = Elevation, b = Slope, c = Temperature, d = Bathymetry, e = Coastline Change, f = Rainfall.

Using the ArcGIS platform's natural break classification technique, the last estimated CVI scores were divided into 5 categories of vulnerability: very high, high, moderate, low, and very low.[17] According to reports, the ordinary break categorization precision is reliable and effective in displaying the geographical pattern of CVI results in the study region.[28]

Table 2. Length of Vulnerable Areas in southwest coast of Bangladesh.

Parameter	Vulnerability Ranking									
	Very Low		Low		Moderate		High		Very High	
	km	%	km	%	km	%	km	%	km	%
Elevation	699.42	20.83	742	22.10	984.18	29.32	678.62	20.21	252.23	7.51
Slope	1243.47	41.02	911.95	30.08	604.06	19.92	226.17	7.46	45.62	1.50
Temperature	408	11.30	1310.71	36.30	637.91	17.6	588.38	16.29	665.23	18.42
Rainfalls	325.21	9	1368.67	37.90	736.69	20.40	531.33	14.71	649.14	17.97
Shoreline change	1.15	0.59	67.91	34.67	107.04	54.64	8.17	4.17	11.58	5.91
Bathymetry	36.10	1.57	256.51	11.17	920.65	40.09	813.85	35.44	269	11.71

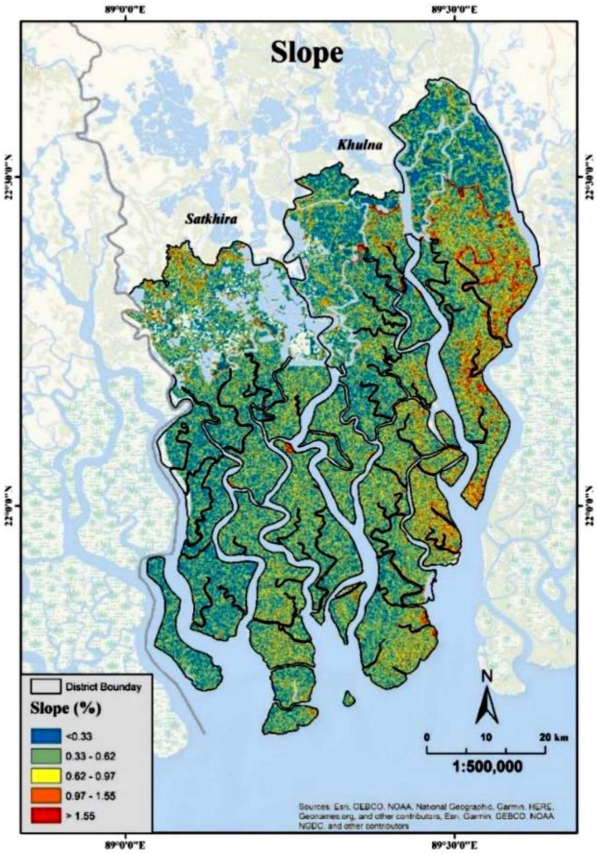

Fig. 4. Slope of Satkhira and Khulna Coast

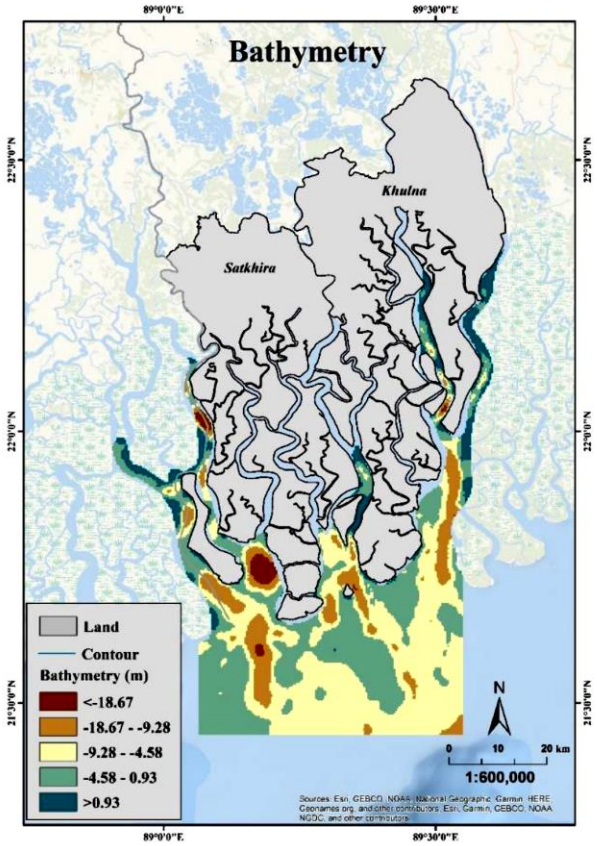

Fig. 5. Bathymetry of Satkhira and Khulna Coast

4. Results and Discussion: Coastal Vulnerability Parameters Mapping

4.1 Elevation Mapping

Lowlands make up the majority of Bangladesh's coastal areas. The coastal elevation in the study region ranges, on average, from 1 to 10 meters. Very susceptible zones were those with altitudes under one meter, whereas low-vulnerability regions had heights of ten meters. With a coastal elevation of 1.91 to 4.84 m, 742 kilometres of the coastline are in a region that is very vulnerable (Table 2). The western reaches of the Sundarbans, Kaliganj, Debhata, and Assasuni beaches are included in this region. There were extremely low- to low - vulnerability sections for a total of 252.23 km of the coastline with a coastal elevation of >10.88 m (Fig. 3). These coastlines run from Dumuria to the eastern edge of the Sundarbans in the Khulna District. There are many different types of high terrain along these coasts.

4.2. Coastal slope Mapping

The coastal regions of Bangladesh have a mild slope. The slope of the research region was calculated using a Digital elevation models with a 10m resolution. Slope percentages with values below 0.33% were rated 5 in this study, while those with values over 1.55% were ranked 1. Table 2 demonstrates that 1243.47 km (91%) of the coasts are extremely susceptible, having a slope of less than 0.30%. 33 km (9%) of the remaining beaches are high- to low-vulnerability regions (Fig. 4). Because these beaches have some high regions, some portions of the Khulna Sadar, Dacope, and Kalaroa coastlines fit within these categories.

4.3. Bathymetry Mapping

The fate of waves is determined by the bathymetry close to the beach.[21] The research area's coastlines have predominantly shallow bathymetric configurations. Grids having a shallow depth (> 0.93 m) were scored 5 and were deemed to be extremely fragile. Grids with substantial depths (-18.67 m), on the other hand, were thought to

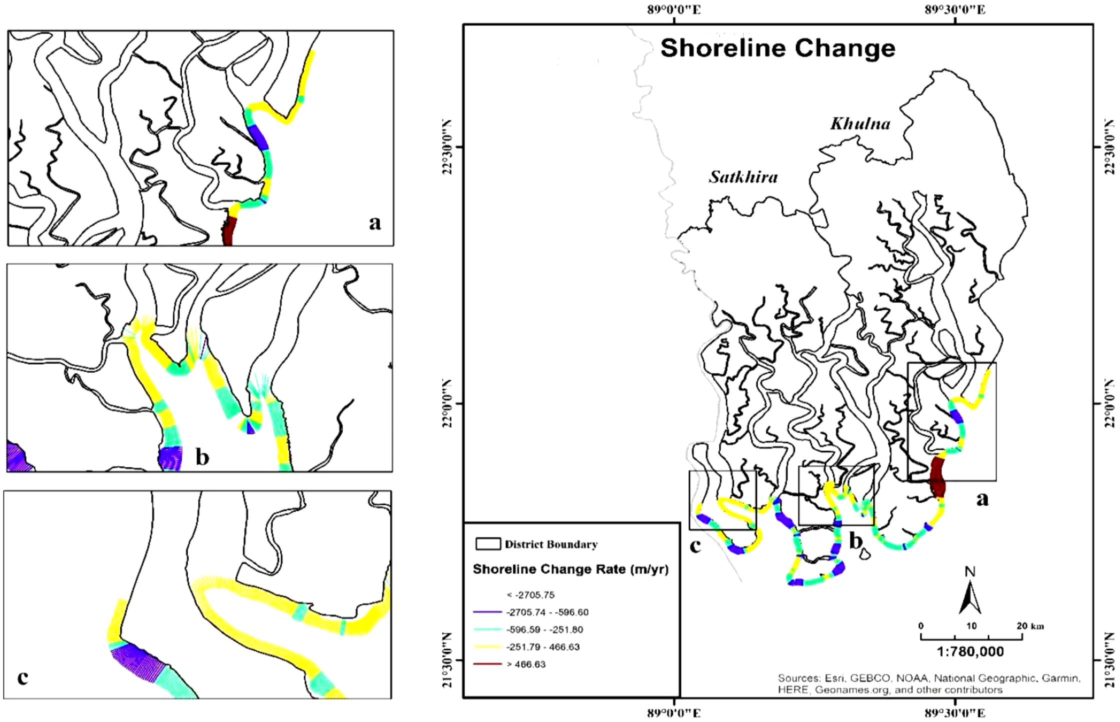

Fig. 6. Shoreline Change of Satkhira and Khulna Coast

have very low vulnerability and were rated 1. Approximately 269.009 (15.5%) and 813.856 (9.1%) km of the coasts are found to be in extremely high- and high-vulnerability zones, respectively, according to Table 2 (Fig. 5). Furthermore, 36.108 (52%) and 256.513 (7.6%) kilometres of the coastline are located in zones of extremely low and low vulnerability, respectively. Some Sundarbans regions have coasts that are quite high and highly vulnerable.

4.4. Shoreline Change Mapping

Coastal dangers are significantly impacted by shoreline change. The research area's coastline change, according to transect-oriented DSAS analysis, ranges between -2,075.75 and 466.63 m/y, with the greatest and minimum erosion rates being -2,075.75 and 0.01 m/y, respectively (Fig. 6). The western region of the Sundarbans has the highest rates of both formation and erosion. Sundarbans has very high rates of erosion and accretion, although the remainder of the shoreline is generally quite stable. Between 1990 and 2012, a total of 1248 km^2 of land were lost to erosion, while 762 km^2 of land were added. Shorelines having a high erosion rate of > -2705.75 m/year were ranked 5 in this study as very high-vulnerability regions. In contrast, shorelines with strong accretion rates (> 466.63 m/year) were ranked 1 and were thought to be very low susceptibility locations. This study discovered that 345 km (17%) of the coastline, with a shoreline change rate between 251.80 and 466.63 m/y, has high susceptibility, while roughly 1248 km (30%) of the coastline, with a shoreline change rate of -2705.63 m/y, has extremely high vulnerability (Table 2; Fig. 6). Parts of the Sundarbans shoreline are covered by these regions. Moderate vulnerability was assigned to a 412 km (29%) long coast from Satkhira to the Sundarbans with a shoreline change rate ranging from -596.60 to -251.80 m/y.

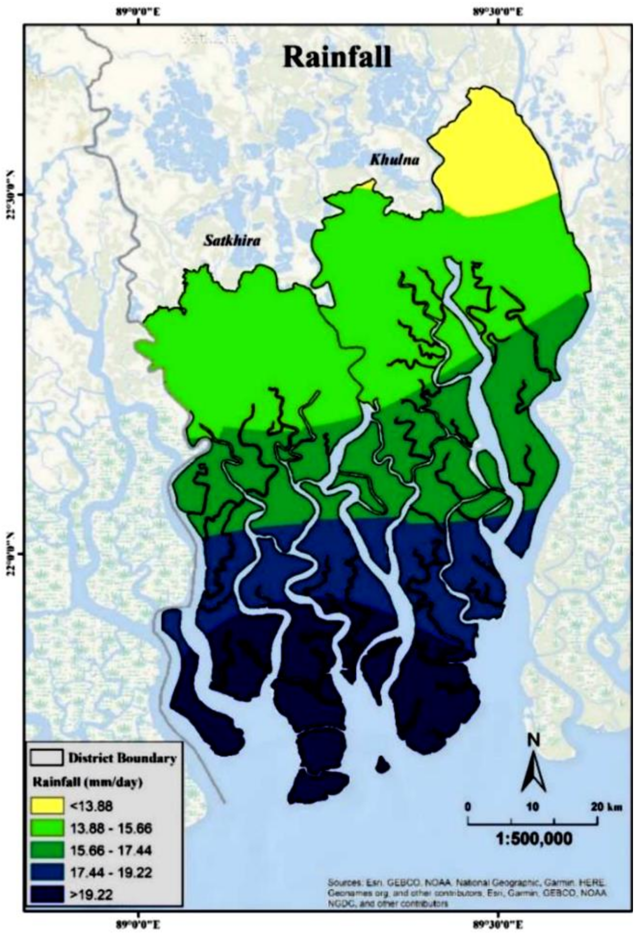

Fig. 7. Rainfall of Satkhira and Khulna Coast

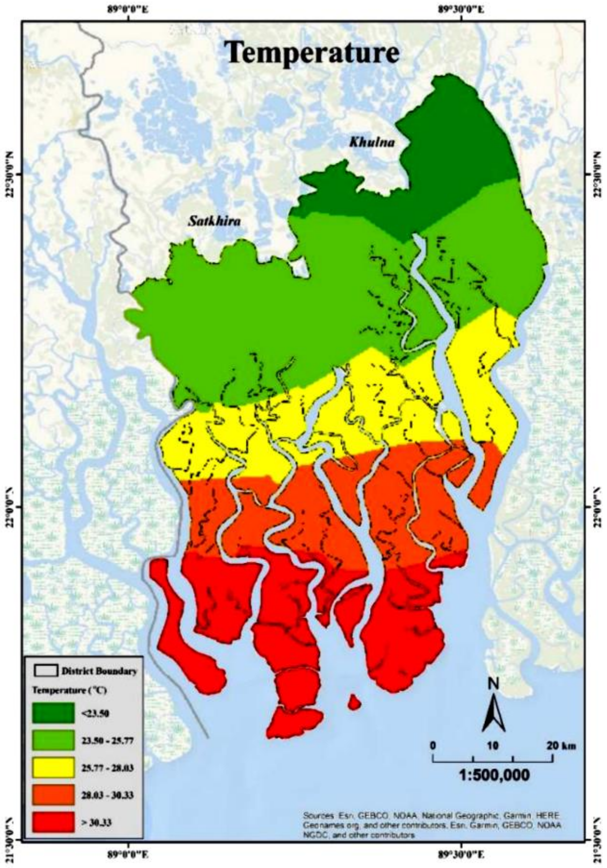

Fig. 8. Temperature of Satkhira and Khulna Coast

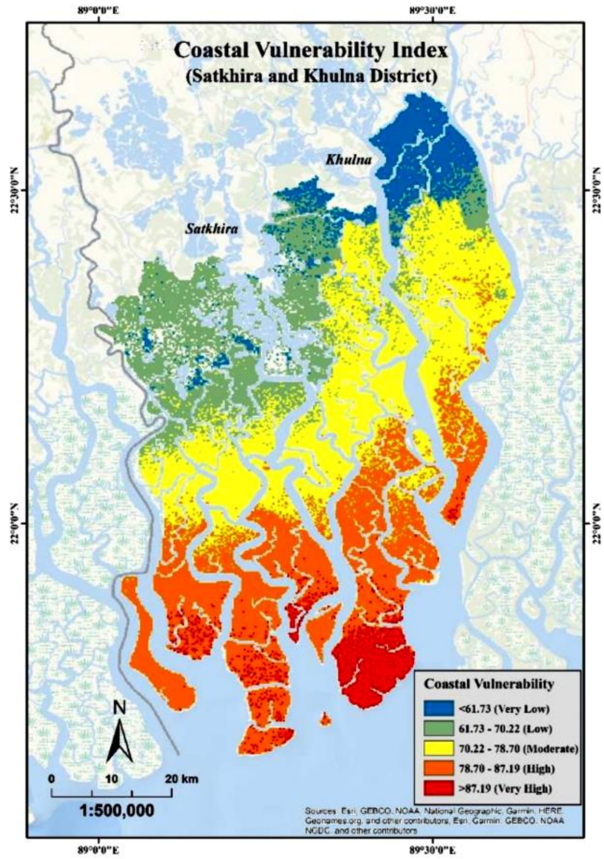

Fig. 9. Coastal Vulnerability of Satkhira and Khulna Coast

4.5. Rainfall Mapping

Rainfall is influenced by temperature indirectly. Whereas temperature and upper air circulation have an impact on the distribution of atmospheric pressure ranges, which seldom govern surface wind patterns unopposed, atmospheric pressure becomes one of the most important elements affecting precipitation. Due to the impacts of average precipitation over 40 years, the south-west coast of Bangladesh was separated into five different impacted zones, as shown in Fig. 7. Due to the concentration of rainfall along the west coast, the location with the greatest average precipitation and highest average surface temperatures is found in the extreme south-west of the research area. The area with the highest average rainfall in these areas, 649.147 sq. km, had more than 19.22 mm of rainfall each day. The research area's northernmost region had the lowest distribution of precipitation, nevertheless. With a surface area of 325.21 sq. km, the average daily precipitation was less than 13.88 mm. The average quantity of precipitation in the other locations ranges from 13.88 to 19.22 mm/day.

4.6. Temperatures

Due to ocean expansion brought on by global warming, sea levels increase. It also intensifies storm patterns. As a result, greater erosion and flooding will have an impact on the majority of the world's coasts. Results of the average air surface temperature of the research region are separated into five impacted areas as shown in Fig. 8. The southwest coastal zone's surface shape has the greatest impact on air surface temperature. The eastern part of the Sundarbans has the lowest average surface temperature, which was lower than 23.50°C, while the south-western region has the greatest average surface temperature, which averaged higher than 30.33°C. The second-highest temperature range recorded in the north-eastern region was 28.05–30.33°C. This ranged from 23.50 to 28.03°C, and most of the research region had a moderate surface temperature. It is evident that the research area's temperature throughout the study period saw a significant geographical fluctuation.

4.7. Calculation of Coastal vulnerability index (CVI)

The Southwest coast's CVI data have a range of 61.73 to 87.19, a mean of 36.02 (both the median and the mode are 30.61), and a standard deviation of 24.19. Five categories of vulnerability were assigned to the final CVI values: very low (61.73), low (61.73-70.22), moderate (70.22-78.70), high (78.70-87.19), and very high (>87.19). Table 2 shows that, of the 377 km of coastline in the research region, around 122 km are in areas with high to very high sensitivity to coastal hazards. The Sundarbans are among these groups of sensitive areas (Fig. 9). The main characteristics of high-to-very high-vulnerability zones include low heights, moderate slopes, high coastal flooding impacts, sandy beaches, high rates of longshore drift, and increased rates of sea level change. But a significant portion of the coastline is located in relatively susceptible regions. This vulnerability group includes 119 km (or 32%) of the research area's coastline. The extremely low- and low-vulnerability zones, on the other hand, cover around 59 (16%) and 78 (21%) kilometres of the coasts, respectively.

The coasts of portions of Satkhira Sadar, dacope Khulna Sadar, etc. are particularly susceptible. Low-to-very low susceptibility zones are affected by steep slopes, high altitudes, low tidal ranges, low storm surge heights, and low erosion rates.

5. Conclusions

The effects of global warming, particularly shoreline change, on Bangladesh's southwest coastal zone has been analysed by computing the Coastal Vulnerability Index (CVI) and verifying and forecasting vulnerability using Machine Learning language and ArcGIS. For the CVI model simulation, nine significant essential climatic factors have been taken into account. In order for the computed values of CVIs to produce objective findings, every parameter has been examined and ultimately classed. For several scenarios including the modification of the shoreline, the possible implications of climate change have been examined. To determine the state of erosion and the pace of coastline accretion, the study examined time series data from the 32-year period (1990–2022) in detail.

The study's goal was to model and determine CVI for Bangladesh's western coastal zone. The Ganges basin's northwest region is particularly vulnerable to natural disasters. Mangrove forests are essential for coping with climate sensitivity (7% changes in land from research findings). The study's 364.7 sq. km. in the northwest is more susceptible to climate change than the rest. The findings of the study indicate that Satkhira and Khulna are the most susceptible areas, where residents are particularly exposed to storm surge and tidal floods. As a result, the likelihood of vulnerability grew over time higher in the southwest coastal regions.

Conflicts of Interest

The authors declare no conflict of interest.

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