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Assessing the Vulnerability of Sea-Level Rise on Cox's Bazar Coastline: An Analysis Using GIS Technology

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Abstract: Bangladesh, with its low elevation, dense population, and reliance on natural resources, is particularly susceptible to global warming and climate change impacts. As sea levels rise, coastal areas face numerous challenges, including increased risk of cyclones, flooding, erosion, and storm surges. The southeastern coastline of Bangladesh, specifically Cox's Bazar, which is the longest sea beach, is particularly vulnerable to these effects. This study aimed to understand the impacts of rising sea levels on Cox's Bazar by creating a Coastal Vulnerability Index (CVI). The CVI was developed by evaluating shoreline changes and geomorphological classes along the shoreline and identifying eight parameters contributing to the area's vulnerability. Geomorphology, slope, relative sea level rise rate, mean tide range, coastline erosion and accretion, land use and land cover, demographic age distribution, and demographic income distribution were among these factors. The researchers used GIS and remote sensing techniques to rank the parameters based on their potential impact on coastal changes and calculate the final CVI. The study's findings indicated that 20% of the shoreline's 342.54 km, or 76 km, was at very high risk, 12% was at high risk (46 km), 24% was at moderate level risk (89 km), and 44% was at low ranked risk (166 km). The most susceptible coastal areas were mainly located near Sabrang and Shahpurir Dwip's southern coasts.

Keywords: Cox's Bazar, coastline, vulnerability, GIS, remote sensing.

1. Introduction:

With a rise in global temperature of 0.6°C at a rate of 0.2°C over the past three decades, greenhouse gas emissions are thought to be the primary cause (Hansen et al., 2006; IPCC, 2007; Rosenzweig et al., 2008; Wood, 2008). An estimated 0.8°C of global warming has occurred over the last century. One of the most well-known impacts of climate change caused by global warming is the rise in sea level, known as eustatic sea level rise (Allen and Kumar, 2006). The possible issue of sea level rise has drawn attention to Bangladesh, a nation with low-lying coastal regions (Sarwar, 2013). Around 1000 kilometers of Bangladeshi coastal land and its population could be significantly impacted by a predicted rise in sea level of 1 meter in the twenty-first century (Cruz et al., 2007). This may cause severe cyclones, uneven storm surges, frequent changes in channel courses, flooding, coastal erosion, and water quality degradation in aquifers. Bangladesh's

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coastline is not equally vulnerable to sea level rise, with the Cox's Bazar coastline being particularly vulnerable due to the complex topographical and social changes resulting from human intervention, including the Rohingya influx (Sarwar, 2013).

Physical features, including low tidal flats, muddy and soft fluviotidal deposits, floodplain deposits, and supratidal plains, significantly contribute to how vulnerable Bangladesh's coasts are to sea level rise. Elements including overcrowding, haphazard development, urbanization, industrialization, and tourism have also heightened the region's vulnerability. Comprehensive coastal zone management is crucial for minimizing the effects and establishing practical adaptation plans in this situation.

Vulnerability assessment is necessary to manage coastal zones susceptible to sea level rise effectively. And the Coastal Vulnerability Index (CVI) can be used to accomplish this. Through a variety of physical factors, such as coastal morphology, relief, geology, relative sea level changes, shoreline change record, tide, and wave regimes, etc., there have been multiple attempts to quantify coastal vulnerability and assess the risk of sea level rise (Gornitz, 1991; Doukakis, 2005; Diez et al., 2007; Nageswara Rao et al., 2008; Abuodha and Woodroffe, 2010). To efficiently run the CVI and manage massive datasets, geospatial techniques like remote sensing and Geographic Information Systems (GIS) have been deployed in the past. Positional precision is a crucial problem in substantial vulnerability mapping and can be solved using geospatial techniques.

The present study concentrates on the quantitative assessment and classification of vulnerability at several locations along the Cox's Bazar coast using a combination of physical, geophysical, and socio-economic characteristics with GIS methodologies. The research aims to identify coastal vulnerability due to rising sea levels and understand the responsible coastal characteristics and sociodemographic conditions. The study has three objectives: (i) to explore the rate of shoreline change along the Cox's Bazar coast; (ii) to identify the geomorphological classes of the Cox's Bazar coast; and (iii) to classify the degree of vulnerability at various parts of the Cox's Bazar coast.

To fulfill the objectives of this research, some research questions have been identified. These questions are organized based on the following objectives (see Table 1):

Table 1: Objective-based research questions of the study.

Objectives	Research Question	Possible Outcome
1. Shoreline change rate along Cox's Bazar coast	a) What is the trend of shoreline evolution?	a) Shoreline evolution map
2. Geomorphological classes of Cox's Bazar coast	a) What are the geomorphological classes of Cox's Bazar coast	a) Geomorphological classes map
3. The magnitude of vulnerability at different Cox's Bazar coast locations	a) What are the factors responsible for coastal vulnerability? b) How do the identified triggering factors affect the coastal vulnerability of the study area? c) How much area is vulnerable due to sea level rise?	a) Identification of coastal Vulnerability factors b) The coastal vulnerability Index table of the study to identify the effects of triggering factors c) Coastline vulnerability map

2. Study Area:

Cox's Bazar is a long, narrow district in southeast Bangladesh that is bordered to the west by the Bay of Bengal and to the east by the Naf River, which also serves as the boundary to Myanmar.

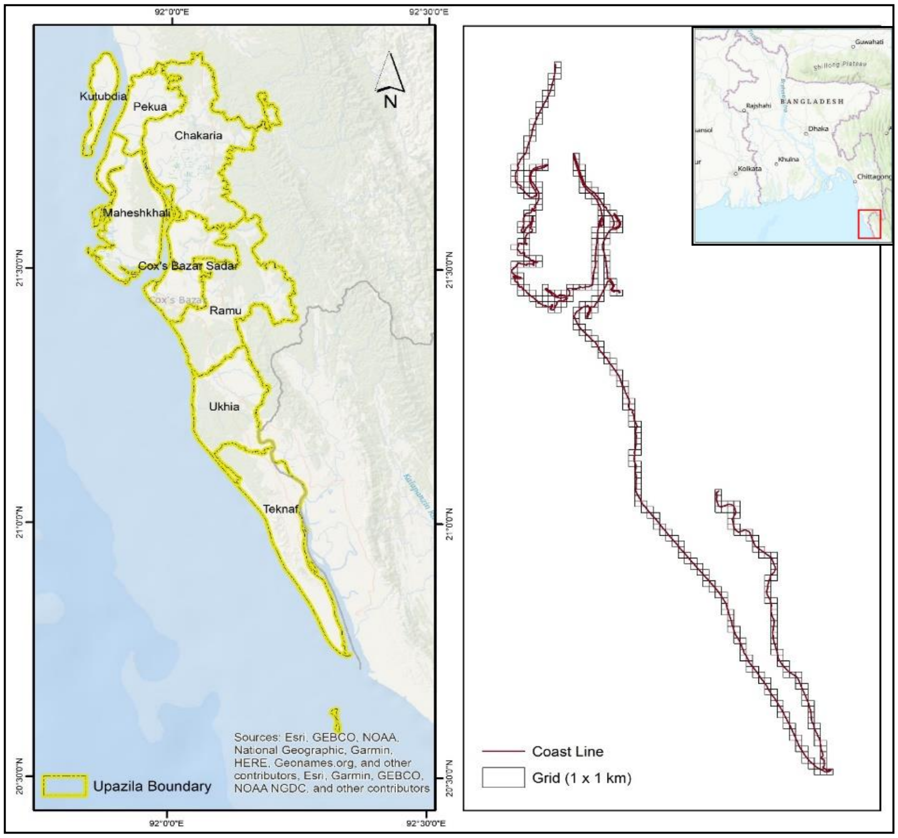


Figure 1: *Location Map of Cox's Bazar Area (source: author, 2023).*

The district comprises several islands, but only two larger inhabited islands, Maheshkhali and Kutubdia, are excluded from this study for computational reasons. The region has challenging topography, poor road conditions, and limited infrastructure. The district mostly comprises low-lying areas crisscrossed by streams draining into the Bay of Bengal. Its coastline boasts the longest stretch of sandy beach globally.

3. Data sources:

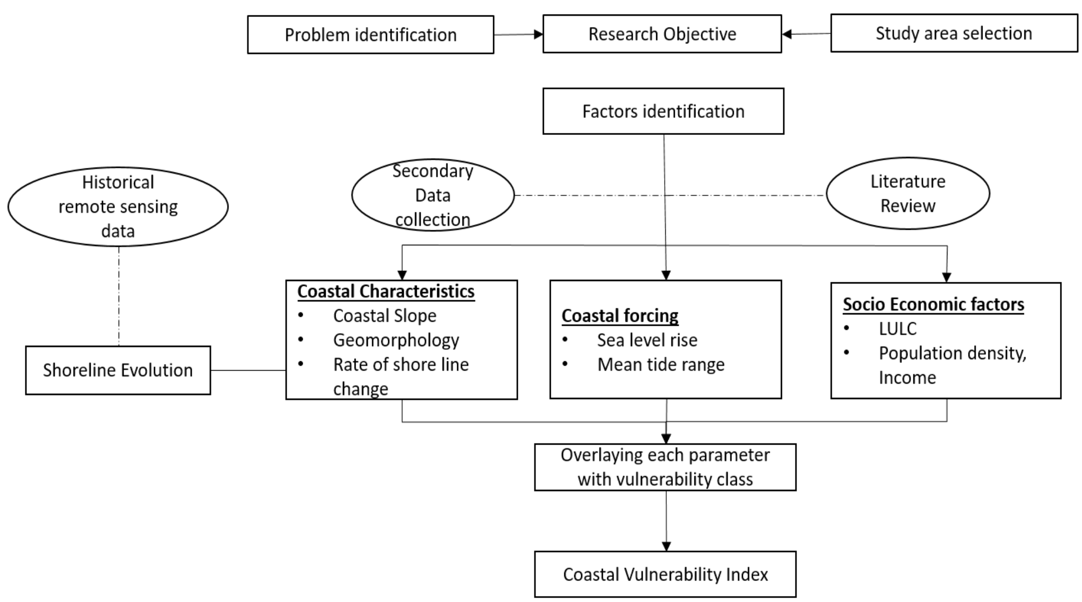
Secondary information was gathered for this study, including demographic information, mean sea level data, and satellite imagery (Landsat 8, DEM). The ASTER v3.0 portal was used to collect the Digital Elevation Model (DEM) data. The USGS's (United States Geological Survey) Earth Explorer contributed with the Landsat data. Demographic data was collected from DRR (Disaster Risk Reduction) team, Humanitarian Crisis Management Programme, BRAC. A list of secondary data and their sources is given in Table 2.

Table 2: List of secondary data and data sources.

Parameters	Method	Source
Geomorphology	Visual Image interpretation (digitization)	Landsat 8 & Aster DEM
LULC	Supervised Classification	Landsat 8
Shoreline Erosion/Accretion	Digital Shoreline Analysis System (DSAS)	Landsat 8
Slope	Spatial analyst	Aster DEM
Sea level change	Regression analysis (30 years monthly mean tide data)	Permanent Service for Mean Sea Level (PSMSL)
Mean tide range	An average tide difference (30 years of tide data)	Permanent Service for Mean Sea Level (PSMSL)
Socio-economic Data	Age range, Income range	Field survey collaboration with BRAC

4. Methodology:

The following figure gives a framework for the overall study method. Major analysis processes are detailed following:



Prepared by: author, 2023

Figure 2: *Flowchart of the methodology.*

4.1 Explore Shoreline Change Rate along Cox's Bazar Coast

The USGS's free software extension tool, the Digital Shoreline Analysis System (DSAS), was used to conduct the analysis for the study. Shoreline change statistics were calculated using vector data and DSAS Version 1.0. With the help of a time series of coastline data that was kept in a Geographic Information System (GIS), the analysis sought to identify the computed shoreline rates of change.

To create the baseline and historical coastline, a continuous line was drawn using a GIS digitization tool at the sea edge to avoid sharp edges along the enveloping polygon. A geodatabase that has all the data required for the processing is the initial input the DSAS system needs. The baseline and historical shoreline vector data are required to be included in this geodatabase. The relative land position (right or left) and baseline placement (onshore, offshore, or intermediate) must be indicated in the baseline parameters as a vector polyline shapefile. In this project, the DSAS baseline placement, which can be either landward or seaward, was set to seaward. The smoothing distance was 5 meters, and the baseline position was always offshore. The distance between transects was also 5 meters.

4.2 Geomorphological Classes of Cox's Bazar Coast

When determining the effects of sea level rise or the degree of coastal vulnerability, the form of the coastal plain is crucial (Nageswara Rao et al., 2008). It also displays the area's ability to withstand erosion from powerful wave energy (Thieler and Hammar-Klose, 1999). To develop their map, the authors relied on the visual interpretation of satellite images like Landsat 8 and ASTER DEM, which have a 30-meter spatial resolution. Each 500-meter pixel was individually mapped through a meticulous identification process. In addition, they utilized Google Earth's high-resolution satellite images, which offered the ability to view past satellite images and topographical information.

4.3 Coastal Vulnerability Index (CVI)

Thieler and Hammar-Klose (1999), Doukakis (2005), and Diez et al. (2007) 's earlier study served as the foundation for the formula used to generate the Coastal Vulnerability Index (CVI). The CVI was calculated by taking the square root of the sum of the rankings for each of the eight parameters, which were assigned values between 1 and 5, and dividing it by the total number of parameters taken into account. The majority of these variables are dynamic and collected from various sources. The variables are (a) geomorphology, (b) slope, (c) relative sea level rise rate, (d) mean tide range, (e) coastline erosion and accretion, (f) land use land cover (LULC), (g) demographic age distribution, and (h) demographic income distribution. The formula for CVI calculation is given as,

$$\mathrm{CVI} = \sqrt{\frac{F_1 * F_2 * F_3 * F_4 * F_5 * F_6}{6}}$$

A variety of geospatial methods were utilized in this analysis. Slope maps were produced using the spatial analysis tool in ArcGIS 10, with corrections applied using a median filter to remove any artifacts from the DEM file. Utilizing Landsat ETM+ imagery of 2013, the geomorphology map was generated through visual interpretation and stored in a shape file. Determining the shorelines for erosion and accretion estimation was challenging, and imagery with a 10-year interval gap was used. High water time imagery was specifically collected for change detection to eliminate misinterpretation of the land-water boundary. Using data from tide gauges dating back the last 30 years, the relative sea level change rate and mean tide range values were determined. Sociodemographic records were obtained from BRAC and interpolated using the Inverse Distance Method.

The study aimed to assess the vulnerability of the Cox's Bazar area. A grid of 1 km x 1 km was created based on the 2013 Landsat ETM + image of the present shoreline (Figure 1). Each parameter's data was categorized into 1 to 5 vulnerability classes, with 1 denoting low vulnerability and 5 denoting extreme susceptibility. While the values for the other parameters were manually assigned for each grid, the mean values of slope and population were derived using the Zonal Statistics tool. By taking the square root of the product of the ranked variables divided by the total number of factors, the final Coastal Vulnerability Index (CVI) was determined.

5. Result & Discussion:

5.1 Shoreline Change Rate along Cox's Bazar Coast

The DSAS analysis of Landsat-8 images from two different time periods, 2000 and 2020, reveals a trend towards erosion (70%) in the urbanized areas of the Teknaf coast (Figure:3). The shoreline changes over time indicate a higher rate of erosion in the north sector (8m/yr) compared to the south sector (13m/yr), and limited zones of accretion with an average rate of 8 m/yr in the north and 5 m/yr in the south. This evolution of the coastline is influenced by both natural and human factors that sometimes work together and sometimes work against each other to control the dynamics of the coastline.

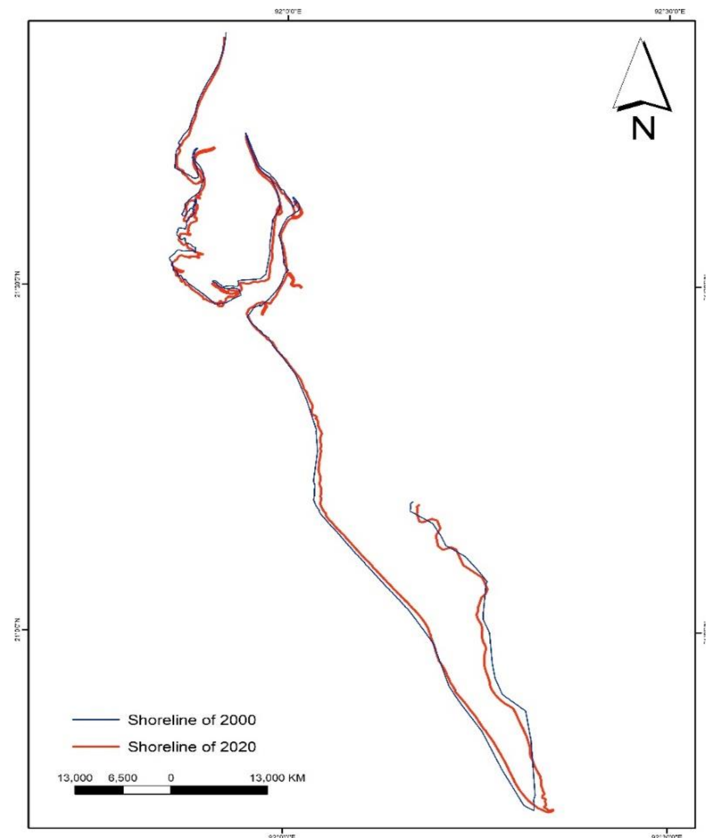


Figure 3: *Coastline change rate alone Cox's Bazar district (source: author, 2023).*

The most significant drivers of this evolution, which have increased the coast's vulnerability to storm surges, are the hardening of the coastline, the scarcity of sand caused by the limited sediment discharge from rivers, and the over-extraction of sand from dunes and beaches. Additionally, the increased frequency and intensity of storm surges, potentially linked to global warming, could explain the high erosion rate seen in the survey's latest time period.

In conclusion, over the past 20 years, coastal erosion has reduced the size of the beaches, making them more susceptible to rising sea levels. According to the change detection results, approximately 45.25 km of land has been eroded, while 13.014 km has experienced accretion.

5.2 Geomorphological Classes of Cox's Bazar Coast

The coastal plain's geomorphology is crucial in understanding how sea levels will change and how resistant the land will be to erosion from string waves. According to the study, all of the geomorphic units in the region are made up of Holocene coastal sediments and are hence relatively erosive. The main coastal landforms, ranked from low to high

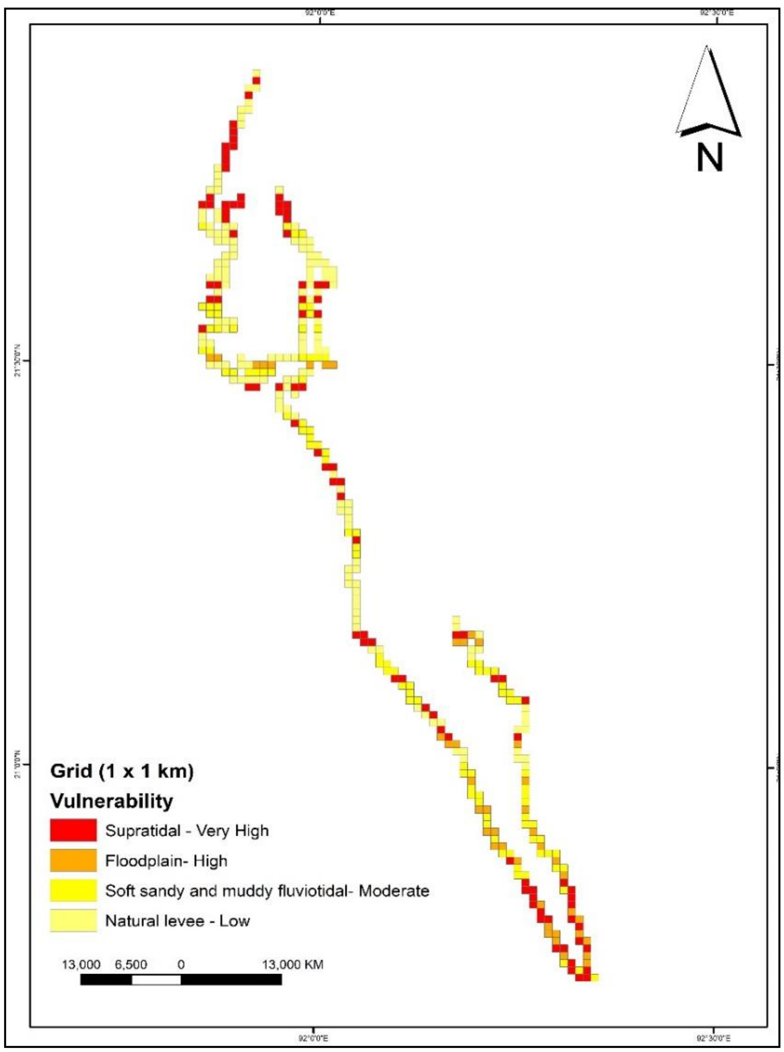


Figure 4: *Geomorphology Vulnerability ranking in Cox's Bazar district (source: author, 2023).*

vulnerability, include natural levee deposits (windbreaks), soft sandy and muddy fluvio-tidal deposits, floodplain deposits, and supratidal plains.

The northern portion of the zone is characterised by fluvio-tidal plains with a complex network of ridges and swales and is composed of slightly oxidized silt and sand. Although heavy waves do not usually flood this area, the middle section of the coast is characterised by well-developed natural levees and abandoned channels made primarily of compact silty clay. It also has a relatively high elevation (more than 3 meters).

It comprises supratidal flats that are dominantly clayey and drained by numerous tidal creeks. Tidal waters temporarily inundate this unit during the rainy season. With an average elevation of 1.7 meters, the southern portion of the coast gradually slopes into the water. Despite the high accretion rate in this region caused by the substantial upper estuary sediment intake, frequent flooding makes this shoreline more vulnerable.

According to a map of the Cox's Bazar coastline in terms of geomorphology (Figure 4), most of the area is comprised of natural levee deposits (39%), assigned a vulnerability rank of 2. Supratidal plains, which occupy 25% of the coast, were assigned a rank of 3, intertidal areas (12%) were assigned a rank of 4, and lateral bars (24%) were assigned a rank of 5 (Table 3).

5.3 Coastal Vulnerability Index (CVI)

5.3.1 Parameters and their Ranking

Eight variables were used to create the final Coastal Vulnerability Index (CVI), which was graded according to how likely they were to result in physical changes to the shoreline due to sea level rise. As described in the following sections, the entire shoreline was separated into sections and given vulnerability rankings ranging from 1 (extremely low) to 5 (very high).

1.3.1.1 Geomorphology: Figure 4 illustrates the Cox's Bazar coastline in terms of geomorphology, showing that 377 cells mapped as natural levee deposits (39%) were assigned rank 2, 96 cells mapped as the supratidal plain was assigned rank 3 (25%), 42 cells mapped as intertidal were assigned rank 4 (12%), and 92 cells mapped as lateral bars were assigned rank 5 (24%). (Table 3)

Table 3: Coastal vulnerability index classes for the Cox's Bazar District.

	Ranking of coastal vulnerability index				
	Very Low 1	Low 2	Moderate 3	High 4	Very High 5
Geomorphology	-	Natural levee deposits (wind break)	Soft sandy and muddy fluvio-tidal	Floodplain deposits	Supratidal
LULC	-	Plantation	Barren land with scrubs	Sandy area, mangrove, Cropland	Aquaculture, River, Swamp, Degraded mangrove

Shoreline	0.16 to 0.96 (Accretion)	0 to 0.16 (Accretion)	0 to –0.16 (Erosion)	-0.16 to –0.57 (Erosion)	>- 0.57 (Erosion)
Slope	4.47–2.47	2.47–2.10	2.10–1.78	1.78–1.31	1.31–0.005
Sea level change	-	-	-	5-10	>10
Mean tide range	-	-	-	3-4	2–3
Dominant Age Group	-	20-30	30-40	50-60	>60
Dominant monthly Income Group	>30,000	20,000-30,000	10,000-15,000	5,000-10,000	<5,000

5.3.1.2 Land Use Land Cover: The land cover map shows four classes of land cover in the study area, with an overall accuracy of 89.25% in the supervised classification. The land cover classes are plantation (rank 2-low), barren land with scrubs (rank 3-moderate), sandy areas, mangroves, croplands (rank 4-high), aquaculture, rivers, swamps, degraded mangroves (rank 5-very high).

5.3.1.3 Shoreline: The coastline's erosion and accretion were ranked as follows: rank 1 for 34 cells with very low accretion (9%); rank 2 for 48 cells with low accretion (13%); rank 3 for 44 cells with moderate erosion (12%); rank 4 for 56 cells with heavy erosion (15%); and rank 5 for 196 cells with very high erosion (52%).

5.3.1.4 Slope: An important consideration in determining a region's coastal vulnerability is its slope (Nageswara Rao et al., 2008). The slope gradient affects both flooding susceptibility and the speed of coastline erosion. If the slope is gradual, a more significant portion of the coast is flooded, whereas a steep slope sees less flooding. Cox's Bazar has a gentle slope, and the water from the high tide rushes far inland from the coast. A 30m ASTER DEM (Digital Elevation Model) and the spatial analyst extension of ArcGIS 10 were used to determine the slope of Cox's Bazar. North of Cox's Bazar Sadar, the hill is at its steepest, whereas it is less steep in the south. In terms of the slope variable, 59 cells were mapped as having a very high slope (16%) and assigned rank 1, 62 cells were mapped as having a high slope (17%) and assigned rank 2, 72 cells were mapped as the moderate slope (19%) and given rank 3, 88 cells were mapped as the low slope (23%) and assigned rank 4, and 96 cells were mapped as the shallow slope (25%) and assigned rank 5.

5.3.1.5 Sea level change: The data source for sea level change was tide gauge data from the Permanent Service for Mean Sea Level (PSMSL). 30 years (1980–2011) of monthly tide gauge data from Cox's Bazar Sadar and Teknaf were used to estimate the sea level change rate. A best-fit linear line was generated using the annual mean high tide data and the least squares approach to determine the sea level change rate. When contrasted to Singh's (2002) estimate of 4–7.8mm/year, the resultant relative change in sea level, 11mm/year for Cox's Bazar Sadar and 14mm/year for Teknaf, was deemed to be overestimated; nonetheless, it was consistent with Choudhury et al. (1997), who predicted a sea-level rise of 10-15mm. A change rate greater than the Ganges deltaic coast's average change rate may be caused by seasonal fluctuation and subsidence. Because the sea level in a smaller area does not fluctuate by more than two classes, 145 grids (38%) and 232 grids (62%) were recognized as high and were given rank 5 (Table 3).

5.3.1.6 Mean tide range: The average of high and low tides, known as the mean tide range, is a crucial sign of tide intensity and is connected to both recurring and long-term risks from storm surge and sea level rise (Yin et al., 2012). With a measured mean tide range of 2.05–3.7 m, the coast in the research area is classified as micro tidal (i.e., less than or about 2 m) and semi-diurnal. The ranking of the coast in relation to mean has been used in various ways by scholars depending on the tide range. This study accepted the notion that, as in other studies, the lower the vulnerability, the greater the tidal range (Thieler and Hammar-Klose, 1999; Pendleton et al., 2004). These studies indicate that on a tidal-dominated coastline, there is only a 50% likelihood of a storm occurring during high tide. A storm with a 3 m surge height will therefore stay 1 m below the elevation of high tide for half of a tidal cycle in a macro tidal zone (>4 m tide range). On the other hand, a micro-tidal area is constantly 'near' high tide and is hence exposed to the greatest risk of flooding during storms. Since the mean tidal range in the study area was observed to be 2.05-3.7 m, it was assigned ranks 4 and 5 on the vulnerability scale (Table 3).

5.3.1.7 Socio-economic Data (Dominant Age Group & Dominant Monthly Income Group): In this study, socio-economic data, such as the dominant age group and dominant monthly income group, were also considered in the coastal vulnerability analysis. Most developed coastal vulnerability indices recognize that accumulating socio-economic variables can help define vulnerable areas (McLaughlin et al., 2002). In the present analysis, the population is regarded as one of the key socio-economic variables since people spend money on infrastructure and other precautions, such as storm surges and sudden flooding, which economic variables cannot replace (Dilley and Rasid, 1990; Devoy, 1992; Rivas and Cendrero, 1994). Despite the inherent challenges in ranking socio-economic data on an interval scale, which prevents many advanced studies on coastal vulnerability indices from considering population (Arun and Pravin, 2012), this study included population as a crucial parameter in the final coastal vulnerability index. The dominant age group and dominant income range population in the coastal areas were considered in the study, with higher age groups being associated with higher vulnerability and lower income being associated with higher vulnerability.

5.3.2 Coastal Vulnerability Index (CVI)

The square root of the product mean was used to determine the Coastal Vulnerability Index (CVI) value for each cell. After that, the information was categorized and ranked to be analysed, as shown in Table 3.

Each coastline cell's data was processed in ArcGIS, and each cell's unique ID was assigned in the shapefile's attribute table. With a mean value of 42.40, a mode of 30, a median of 37, and a standard deviation of 20.90, the resulting CVI values for Cox's Bazar vary from 11.61 to 122.5. Figure 5 presents the CVI map.

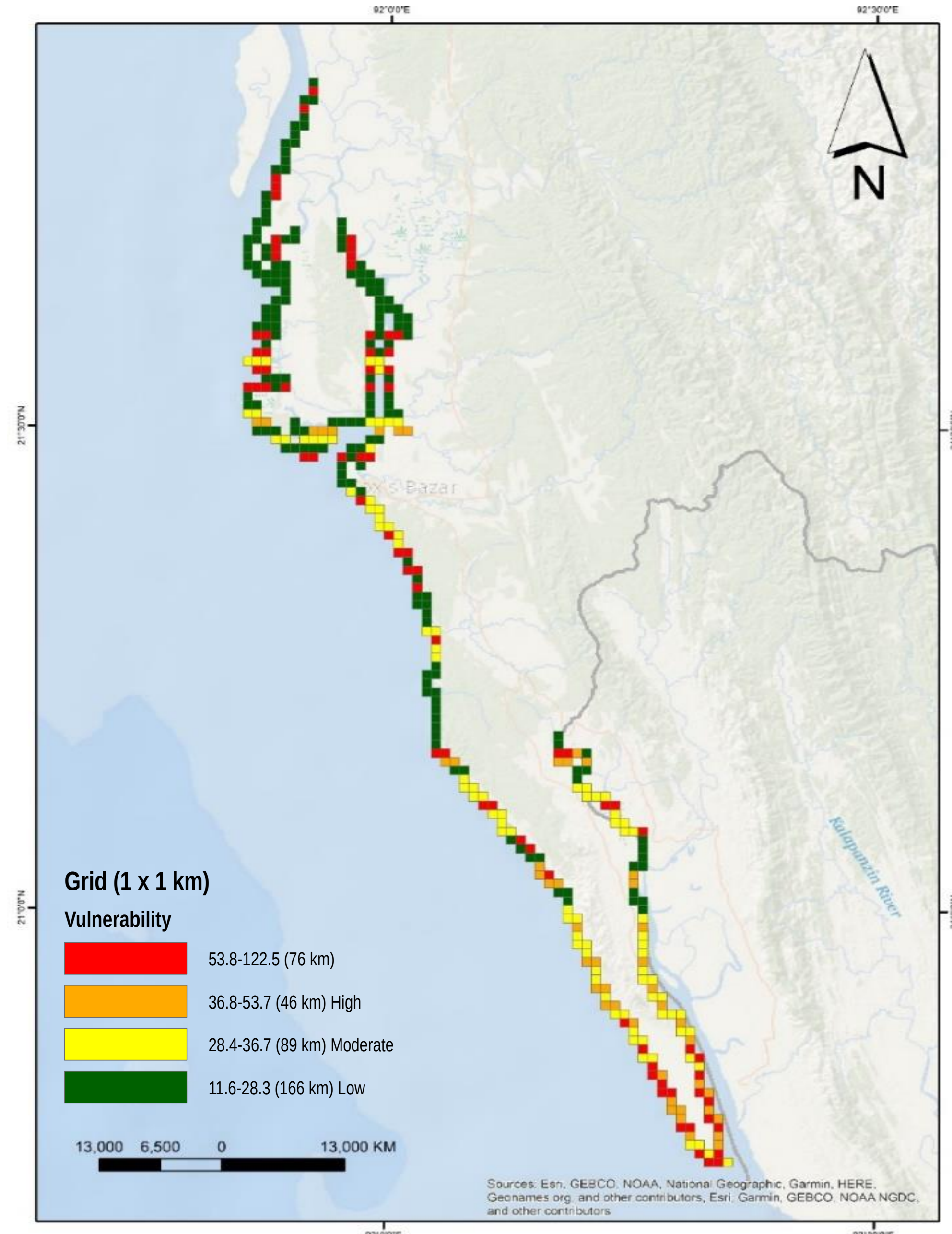


Figure 5: *Costal Vulnerability Index map of Cox's Bazar (source: author, 2023).*

Based on quartile classification, low, moderate, high, and very high vulnerability groups were created from the final CVI scores. According to the percentile division, the 25th percentile showed less vulnerability, up to the 50th percentile was moderate vulnerability, while the 75th percentile showed high and very high vulnerability (Thieler and Hammar-

Klose 1999; Pendleton et al. 2004; Nageswara Rao et al. 2008; Abuodha and Woodroffe 2010). The low vulnerability category corresponds to CVI values below 28.3, the moderate vulnerability category corresponds to values from 28.4 to 36.7, the high vulnerability category corresponds to values from 36.8 to 53.7, and the very high vulnerability category corresponds to values above 53.8. The analysis revealed that specific parameters, including shoreline geomorphology, shoreline erosion and accretion rate, and population, had a significant impact on the final result due to a large number of variabilities.

6. Conclusion:

The goal of determining the coastal vulnerability index (CVI) of Cox's Bazar was to provide insight into the vulnerability of the coastal area to decision-makers and planners. To ascertain the current vulnerability in the study area, dynamic characteristics, including geomorphology, slope, relative sea level change rate, mean tide range, coastline erosion and accretion, land use and land cover, and socio-economic data were examined. However, including pertinent factors like storm surge and wave height could have given a more precise CVI to comprehend the area's risk better. However, socio-economic data were added to the analysis to supplement. By identifying the primary threats to integrated coastal zone management, the vulnerability assessment would assist in achieving sustainable use of coastal resources. Due to Bangladesh's inadequate spatial data infrastructure compared to other developing and developed nations, the aggregation of the above data was constrained. Large-scale vulnerability mapping requires high-resolution data, lacking in this analysis, such as Lidar for elevation data and a more significant number of tide gauge stations for estimating the exact rate of sea level rise and mean tide range. Despite the scarcity of high-resolution data, the final CVI analysis was done with the utmost care. The geospatial strategies employed in this work are reliable instruments that can manage big dataset volumes while saving time and resources. These methods allowed the study to determine that 32% of the study region was made up of very high to high vulnerable zones with severe vulnerability.

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