ASSESSMENT OF REGIONAL SEA LEVEL RISE AND COASTAL VULNERABILITIES ALONG THE COASTAL AREAS OF BANGLADESH

Jannatul Ferdous Eva*[1], Nusrat Anam[2] and G. M. Jahid Hasan [3]

[1] *Graduate Student, Military Institute of Science and Technology, Dhaka, Bangladesh, e-mail: jannatul03.mist@gmail.com*
[2] *Graduate Student, Military Institute of Science and Technology, Dhaka, Bangladesh, e-mail: porna7939@gmail.com*
[3]*Professor, Military Institute of Science and Technology, Dhaka, Bangladesh, e-mail: jahid01@gmail.com*

ABSTRACT

Sea level rise has impacted Bangladesh's coastline zone and its topography in a variety of ways, including inundation, erosion, and saline water incursion into the water table. The hazards to coastal areas would be exacerbated by the possibility of rising sea levels due to climate change. Lack of grasp has resulted in serious misunderstandings regarding the implications of rising sea levels caused by global warming for Bangladesh. At various levels, a variety of studies on the causes, repercussions, and preventive actions of this problem have been conducted. However, there is a dearth of extensive research on the usual trend of regional sea level rise, as well as reliable quantification based on available data, to paint a clear picture of this major challenge that is relevant to Bangladesh. As a result, in this study, an attempt is made to calculate the sea level rise based on long-term historical tidal data at various locations along Bangladesh's coast line. In this research the collected data and the consistency of the available data have been checked discreetly for missing records and removed the local non uniformity manually from tidal variation graph. The analyzing procedure based on Linear Regression method and the collected data has been estimated the trend of sea level rise at different selected stations. It helps to quantify the average sea level rise at different coastal zones of the country. This study has also developed a vulnerability index for the entire coastal areas of the country based on the three physical variables. From this vulnerability index the risk of coastal zone has been identified. Coastal management strategies depend on information on different aspects of coastal ecosystems, processes, resources, natural hazards and their consequences, and government response efficiency. The most important is to have interconnected approaches at the national, sub-national, and local levels in any efforts to ensure the safety, security, and sustainability of coastal communities. And the Bangladesh government has already proceeded on an integrated and holistic project titled Delta Plan 2100 for current and future sustainable development.

Keywords: *Sea level rise, tidal water level, trend analysis, linear regression, coastal vulnerability index*

1. INTRODUCTION

In the past, the main causes for sea level fluctuations were due to natural processes such as orbital variations of earth. However, nowadays the main reason of this problem is clearly humans. Earth is getting warmer day by day due to different kinds of human activities which are led to increase the global warming and this rising temperature leads to raise the sea level and affect the low-lying part of coastal areas of the world.

Bangladesh, situated at the confluence of the Brahmaputra, Ganges, and Meghna rivers, is a densely populated country situated slightly above sea level. These delta regions are home to about 150 million people (Houghton, 2010). The effects of the monsoon and cyclonic storms create a hazard for Bangladesh. In Bangladesh, these storms result in severe flooding and sea level rise, which obviously affect a large number of people.

Bangladesh is a coastal nation that extends 710 kilometers along the Bay of Bengal coast. As a result of sea level rise, the country is facing a number of challenges. Bangladesh has already been affected by it in terms of biodiversity loss, saline intrusion, and soil erosion. Future developments will bring considerably greater potential risks. Sea level rise along this coast will have a number of negative effects, including floods, saline intrusion, crop failure, infrastructure damage, devastation of fisheries, and loss of ecosystems. A one-meter rise in sea level will have an impact on the country's huge coastal territory and flood plain zone. It will have an impact on the Millennium Development Goals, resulting in environmental refugees. Coastal resources, water resources, agriculture, and Bangladesh's ecosystem are the most vulnerable sectors to a one-meter sea level rise.

Understanding the definition of "vulnerability" is important for understanding the causes of Bangladesh's severe sea level rise effects. In the face of disasters, vulnerability results from the interaction between people and their surroundings. Bangladesh's low-lying location makes it extremely susceptible to rising sea levels. 80% of the nation is prone to flooding. Furthermore, this nation's economy is underdeveloped. According to Agrawala (2003), this country's high susceptibility is caused by a combination of low-level development, climate, and topography. This country has a high population density, which raises the possibility of mitigating the effects of sea level rise on surrounding nations. Sea level rise will have an impact on agriculture, which accounts for one-fifth of the economy of the country. Vulnerability is also correlated with the number that are impacted by a threat and their capacity for adaptation. As a result, the true relevance of vulnerability in disaster literature and the development community declined when the phrase was utilized in CVI research, which primarily examined a coast's physical vulnerability. Vulnerability may be ascertained by combining sensitivity with the population, the impacted environment, and their adaptive response variable.

In the past studies the Sea Level Rise estimation processes was not so good for analysis. The errors of tidal records did not check properly. In this study the consistency of the tidal records has been checked properly. And the coastal vulnerability along the coastal areas of Bangladesh has been estimated for taking necessary steps to rescue the coastal zones from the risk.

2. METHODOLOGY

The general impartial of this study is set as below:
a. To estimate monthly, seasonally and yearly variation of regional sea level along the coastal areas of Bangladesh.
b. To identify the vulnerable zone along the coast line of Bangladesh.

2.1 Study Area

The Bay of Bengal and the Ganges-Brahmaputra-Meghna (GBM) river system control the coastal zone of Bangladesh in terms of hydrology and geomorphology. The extent of Bangladesh's coastline zone is 47,201 km2, or 32% of the nation's total coastline (Figure 1). About 35 million people, or 29% of the total population, live in the coastal zone. Bangladesh has 19 coastal districts: Jessore, Narail, Gopalganj, Shariatpur, Chandpur, Satkhira, Khulna, Bagerhat, Pirojpur, Jhalakati, Barguna, Barisal, Patuakhali, Bhola, Lakshmipur, Noakhali, Feni, Chittagong, and Cox's Bazar. Geographical features divide Bangladesh's coastal zone into three sections: the eastern zone, the central zone, and the western zone.

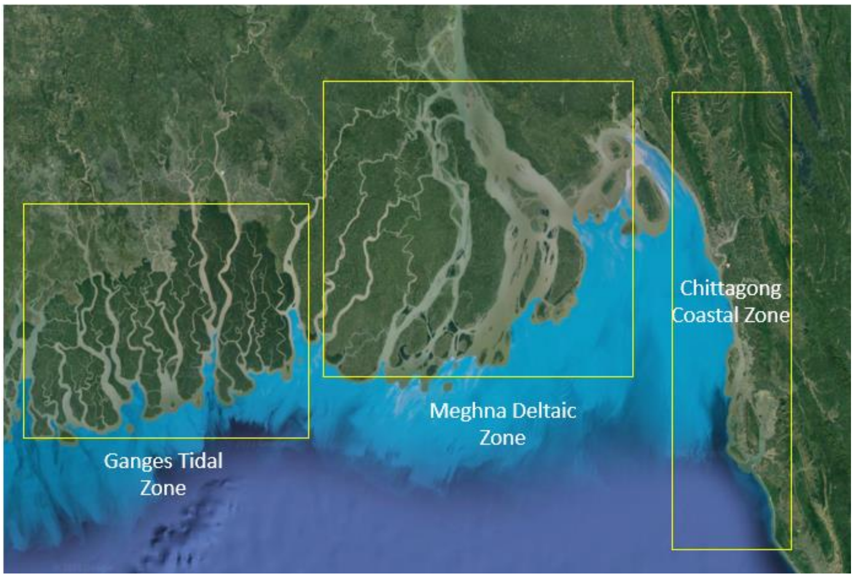

Figure 1:Coastal zone of Bangladesh based on geomorphology and hydrology

2.2 Linear Regression Analysis of Tide Records

Linear regression is a method for modeling the relationship between a scalar response (and dependent variable) and one or more explanatory variables (or independent variables) using a linear approach. In linear regression, data is used to identify the unknown model parameters of linear predictor functions, which are used to model relationships. Quantifying the relationship between one or more predictor factors and one result variable is done using linear regression. A common method for modeling and predictive analysis is linear regression. The use of linear regression in analysis is important. The technique plots a trend line in a series of data points using statistical computations. Regression analysis has three key applications: identifying predictor strength, anticipating an effect, and predicting trends. These regression estimates are used to explain the relationship between one dependent variable and one or more independent variables.

The simplest form of the regression equation with one dependent and one independent variable is defined by the formula

$$y = c + b\,x \qquad (4.1)$$

Where,

y = estimated dependent variable score

c = constant,

b = regression coefficient, and

x = score on the independent variable.

(4.2)

$$b = \frac{n\sum xy - \sum x \sum y}{n\sum x^2 - (\sum x)^2}$$

$$c = \bar{y} - b\,\bar{x} \tag{4.3}$$

Where,

$\bar{x}$ = mean of the independent variable

$\bar{y}$ = mean of the dependent variable

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \tag{4.4}$$

For each of the identified tidal stations, specific correlations between water level and time were accordingly created. The coefficient of determination (r^2) was computed in order to evaluate the accuracy of the fit of the regression relationships. The relationship between the parameters and time is shown by the coefficient of determination (r^2). A poor correlation between the parameters and time is shown by a low coefficient of determination (r^2) for the parameter. The trend pattern showed how the parameters are either increasing or decreasing with respect to time. Trend line analysis was performed using Equations 4.1 and 4.4.

2.2.1 Data Prepossessing For Linear Regression Analysis

The collected data and its consistency as well as methods used for selected areas of three coastal zones (western, central and eastern zone). The raw data has been taken from Bangladesh Water Development Board (BWDB) and Bangladesh Inland Water Transport Authority (BIWTA) from 1960-2018. From these stations, 19 water level stations have been selected along the interior and exposed coasts covering three major geo-morphological regions. However, accuracy checks revealed that seven of the initial 19 stations were discarded due to inconsistencies in the results and 12 stations which has been selected for analysis of sea level rise. Besides, percentage of missing data and their quality has been checked. Daily high and low tidal water levels are collected from BWDB and hourly tidal water levels are collected from BIWTA. Daily high and low values were calculated from the hourly data. The daily, weekly, monthly and yearly graphs were plotted with tidal data. The consistency and continuity of these were checked. While checking consistency of tidal water level the spikes and aberrant data were removed. Linear trend analysis was done by finding the yearly average of maximum and minimum tidal water level. The estimated trends are compared with the stations to determine the rate of sea level change.

2.3 Coastal Vulnerability Index

One of the most common and simple tools for evaluating coastal vulnerability to increasing sea levels is the Coastal Vulnerability Index (CVI), which focuses primarily on erosion and inundation (Sawar, 2011) is often the initial methodological step in the CVI formulation estimation process. The second stage is to quantify the defined primary variables. Quantification for this step can be done in a number of ways, but it typically depends on the idea of semi-quantitative scores on a 1–5 scale (Table 1), where 1 indicates a main variable's low impact on coastal vulnerability for the studied region or sub-areas and 5 indicates a high contribution. In the third step, primary variables are combined using a mathematical formula to create a single index. As a last step, CVI values are divided into various categories. Vulnerability assessments are desperately needed along extremely populated coastlines, like Bangladesh, despite the effectiveness of these assessments and the difficulties posed by sea level rise and the effects of climate change.The cumulative vulnerability of each of these variables may then be used to assess the overall vulnerability of a coastline.

Table 1: CVI Numbering of vulnerability classification for the coastal zone of Bangladesh

CVI Numbering	Vulnerability Classification
5	Very high
4	High

3	Moderate
2	Low
1	Very Low

2.3.1 Sea Level Rise in Coastal Vulnerability Index

Vulnerability and the rate of sea level rise are closely related. When determining a coastal vulnerability index, the rate of change in relative sea level is a significant component. The majority of research uses the same categories for assessing coastal vulnerability by combining the expected ranges of sea level rise. It shows Table 2.

Table 2: Vulnerability of coastal zone on the basis of sea-level rise (mm/yr)

	Very low	**Low**	**Moderate**	**High**	**Very High**
Sea level rise	<1	1 - 2	2 – 5	5 – 7	7 -9-and over

When the range of sea level changes is narrow along the coast, small intervals are utilized (Dwarakish et al., 2009, Abuodha and Woodroffe, 2010), and big intervals are used (Ozyurt and Ergin 2010). The scope of sea level rise vulnerability analysis is the source of this study (Ozyurt and Ergin 2010).

2.3.2 Tidal Range in Coastal Vulnerability Index

A significant consideration in assessing coastal vulnerability is the tidal range. The difference between the average water level at high tide and low tide for a specific time period is known as the tidal range. The lunar-Earth relationship can affect the tidal range. The difference between the mean low water springs (MLWS) and the mean high-water springs (MHWS) is known as the mean spring range. In the same way, the mean neap range is determined by subtracting mean low water neaps from mean high water neaps (MHWN). The Bangladeshi coast is subject to two high tides and two low tides each day due to the semidiurnal nature of the tides. Almost all CVI research considers every choice as a variable. Table 3 illustrates that the tidal range lessens coastal vulnerability throughout Bangladesh's coast. Tidal submergence is necessary to keep ecosystems functioning normally. Additionally, by recharging topsoil, it benefits adjacent areas of the coastal zone. Consequently, it is thought that the Bangladesh coast is less vulnerable during higher tidal ranges and vice versa.

Table 3: Coastal vulnerability along the Bangladesh coast on the basis on tidal range (m) (Source: Sawar, 2011)

	Very high	**High**	**Moderate**	**Low**	**Very low**
Tidal range (m)	< 3.5	3.5 - 4.0	4.0 - 4.5	4.5 - 5.0	> 5.00

2.3.3 Erosion in Coastal Vulnerability Index

A coast's vulnerability to erosion ranges according to changing conditions along its shoreline. High rates of erosion due to possible sea level rise are less likely to occur on a shoreline that has previously demonstrated a long-term pattern of accretion. A coastal zone is typically divided into five groups according to the degree of erosion vulnerability, as seen in Table 4, which is the result of numerous studies conducted throughout the world that have included shoreline change in the CVI study.

Table 4: Erosion vulnerability classification of the Bangladesh coast (Source: Sawar, 2011)

Very high	**High**	**Moderate**	**Low**	**Very low**

Rapid erosion (>15 m/yr)	Erosion (5-15 m/yr)	Erosion 5 m/yr to accretion 5 m/yr	Accretion (5-15 m/yr)	Rapid accretion (>15 m/yr)

2.3.4 Data Prepossessing For Coastal Vulnerability Index Analysis

BWDB and BIWTA tide gauge data were used to measure sea level rise (SRL) along the coast. The BWDB water level data is presented as daily high and low water levels in meters (m). The mean water level is calculated using BWDB data by averaging the daily high and low water levels in metres, which is then converted to millimetres. The BIWTA data is in the form of mean daily water levels in meters, which have been converted to millimetres. In Excel, the mean annual water level was calculated and plotted. Finally, linear regression was used to determine mean sea level (MSL) trends. The rate of shoreline change has been calculated using the Digital Shoreline Analysis System (DSAS), and the rate of shoreline change along the coast has been estimated using the variations between Landsat TM acquired in 1989 and 2019. The tidal range along the coast has been estimated using tide gauge data from BIWTA. Mean tidal range spring (MTRS) has been calculated by subtracting MLWS from MHWS. Similarly Mean tidal range neap (MTRN) has been calculated by subtracting MLWN from MHWN. Spring tidal range (MTRS) has been used to calculate the vulnerability of the Bangladesh coast.

3. RESULTS AND DISCUSSIONS

3.1 Sea Level Rise

Seasonally and yearly average of daily high, low and mean tidal data were plotted against time to find out the trend of sea level rise for selected station against time using linear regression estimation method. From this analysis, the rate of mean sea level rise at selected station is determined, which is appended below in Figure 2. Figure 2 shows the mean sea level rise of selected stations. From this figure the trend of mean sea level rise is found more irregular in decreasing slope for Khulna and Banigram station and for Patharghata Station the trend of is in increasing slope with high sea level rise (23.1 mm/yr) by the cause of conflux effect. This station is very vulnerable with flood inundation and salinity intrusion. In other stations the mean sea level rise is almost within the range of 4 to 10 mm/yr and their trend is positive. The gentle slope of the land in eastern zone may be the source of this variation. This zone appeared to have more irregular water level patterns than other areas, and data points deviated significantly from the regression line.

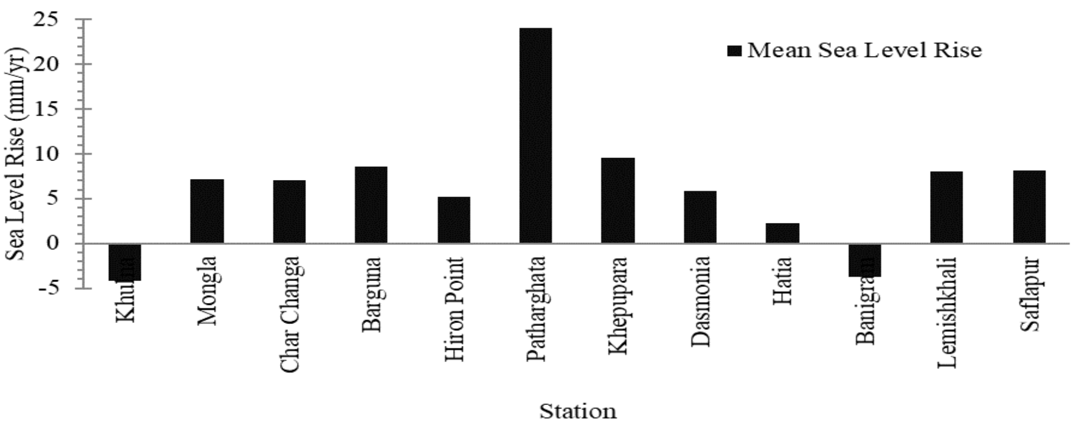

Figure 2: Mean sea level rise (mm/yr) for selected station

3.2 Coastal Vulnerability Index

3.2.1 Sea-Level Rise Vulnerability Of the Coastal Zone Bangladesh

The results of analyzing tidal data at 12 stations (1960-2018) along the Bangladesh coast show significant variation in different areas of the state (Figure 3). Figure 3 shows how much sea level has changed in mm per year at each station. The sea level trend has increased in the western zones of Hiron Point, Mongla, Char Changa, Barguna, and Patharghata, while at Khulna station, SRL has decreased. But Patharghata SRL has become increasingly unusual. This seems to be an exaggeration of sea level rise. The sea level trend has increased at central zone Dasmonia, Hatia, and Khepupara stations. The rest of the eastern zone sea level trend has increased at Lemishkhali and Saflapur, and at Bnigram stations, SRL has decreased.

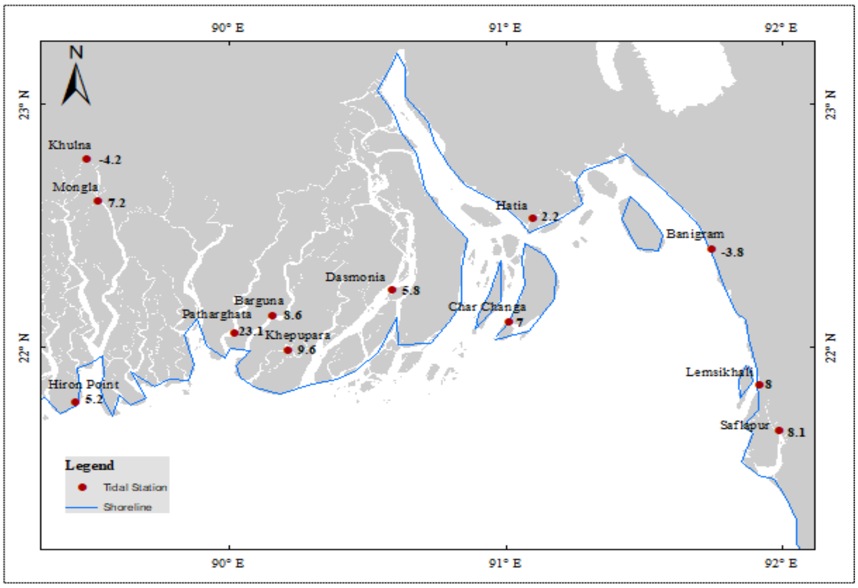

Figure 3: Sea level change at different tidal stations along the Bangladesh coast

Compared to SRL rate, Figure 4 in western zone, Hiron point and Charchanga station vulnerability is high while in Patharghata and Mongla station vulnerability is very high. The khepupara station in the central zone is SRL 9.6 mm/yr which is later in the very high vulnerability category compared to the range in Table 2. Eastern zone Lemishkhali and Saflapur station vulnerability is very high vulnerable coast while in Banigram station vulnerability is moderate.

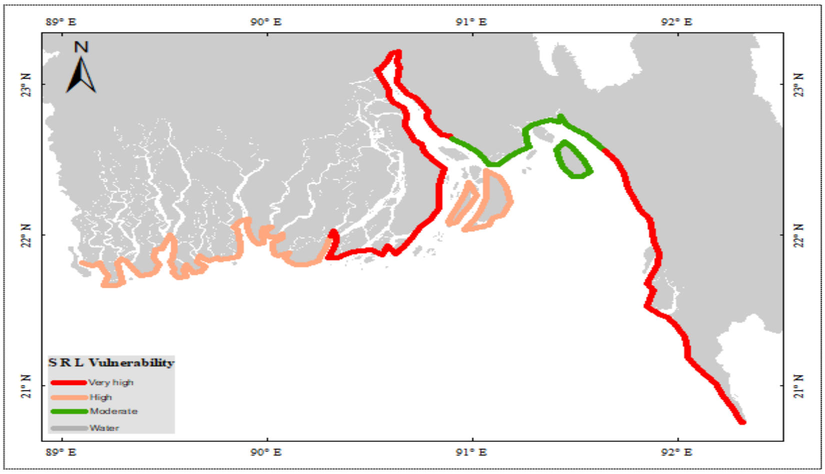

Figure 4: Vulnerability of the Bangladesh coast on the basis of sea level change

3.2.2 Tidal Range Vulnerability Of The Coastal Zone Bangladesh

The stability of the coastal ecosystem is impacted by the tidal effect. Low-lying coastal regions will be submerged by tidal water during the tide cycle. To calculate the tidal range, information regarding the mean low and mean high water levels during spring tides is required. For the tidal range analysis (1960-2018) shown in Figure 5, only 5 stations located on or near the shoreline were chosen. The stations are Hiron point, Khepupara, Char Changa, Sandwip and Cox's Bazar.

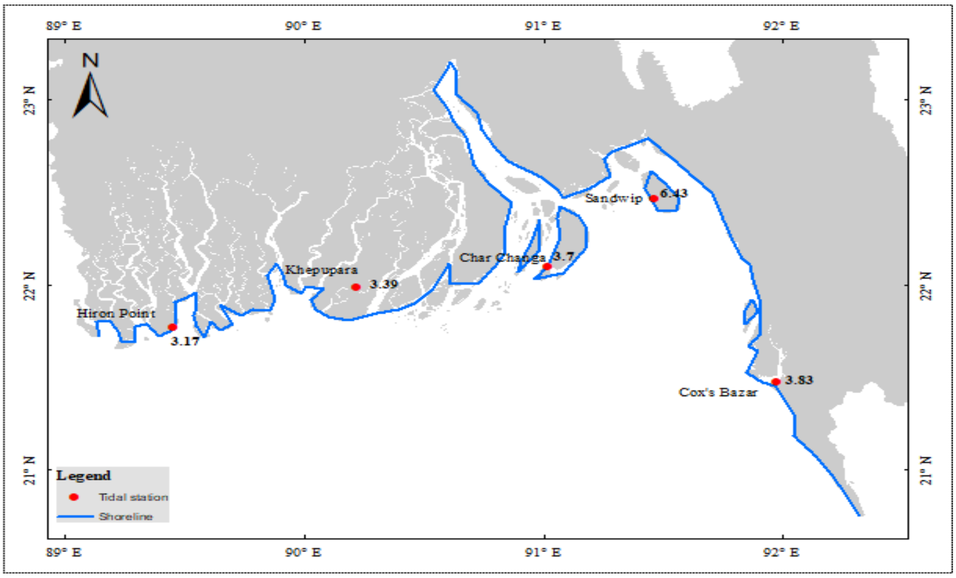

Figure 5: Tidal stations and tidal range on the Bangladesh coast

In Figure 5, the tidal range of the five stations has been plotted using ArcMap. In the ranges were interpolated using the Inverse Distance Weighted method to include a spatial resolution of the mean spring tidal range along the coast.The mean tidal range spring was measured by subtracting the mean low and high water springs. Mean tidal range neap, on the other hand, was measured by subtracting mean low water neap from mean high water neap. The vulnerability of the Bangladesh coast has been calculated using the spring tidal range. Table 6 shows the highest Sandwip station tidal range at 6.43 m. At the hiron point station, the lowest range was found to be 3.17 m. Higher tidal ranges are thought to make the Bangladesh coast less vulnerable, and vice versa. Table 3 shows the vulnerability groups for the coastal zone based on tidal range.Comparing tidal station with Table 3 shows that western zone tidal range is very high and high vulnerable. tidal station shows that eastern zone tidal range is low and high vulnerable. The eastern zone tidal range low and high vulnerable Figure 6 is shown in ArcMap.

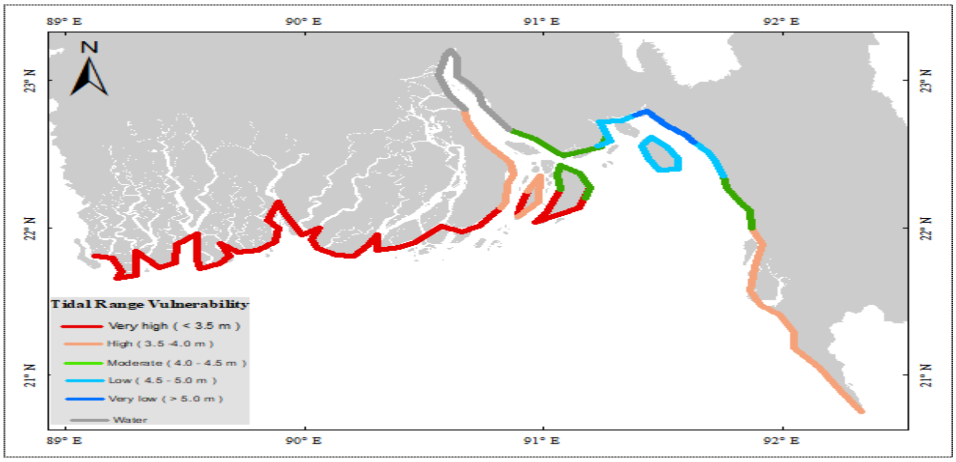

Figure 6: Coastal Vulnerability Index (CVI) of the Bangladesh coast on the basis of tidal range

3.2.3 Erosion Vulnerability Of The Coastal Zone Of Bangladesh

Bangladesh's coastline is especially vulnerable due to the low elevation of the coastlands and the potential for regular shoreline movement. This deltaic shoreline is constantly changing as a result of both more ordinary occurrences like waves, tidal currents, and storms, as well as more extreme ones like cyclones, coastal floods, and sea level rise. Over the course of the 30 years, observations were also made of the overall erosion and accretion regions in the various coastal zones. To outline the coastline over Bangladesh's whole length using the manual digitization approach. From these single-band images, the shoreline was then manually digitized by following the line that separates land from sea. Following the digitization of the shorelines, the USGS's "Digital Shoreline Analysis System" (DSAS) Version 5.0 software extension for Esri ArcGIS was used to calculate the rates of shoreline change along the three distinct coastal zones. A reference baseline, from which the transects are cast, and at least four coastline locations are the fundamental data needed to execute this analysis software. After establishing measurement stations at the intersections of the transects with the shorelines, data on shoreline change was computed. Table 5 gives a summary of the results of the areal and transect-wise study. The shoreline alterations seen in different coastal zones are compiled in the following subsections.

Table 5: Rates of shoreline change and land area subjected to erosion or accretion in various coastal zones of Bangladesh

		Coastral Zone		
		Western Zone	**Central Zone**	**Eastern Zone**
Rate of Shoreline Change along Transects (m/year)	Mean	-5.19	-15.03	3.06
Erosion (Km²)		50.37	124.75	37.95
Accretion (Km²)		9.7	63.06	68.15
Net land loss/gain (Km²)		-40.67	-61.69	30.2

Here, '+' sign indicates shoreline advance (land gain) and '-' sign indicates shoreline retreat (land loss).The coast was divided into five vulnerability groups based on the rate of shoreline change. the vulnerability classes are group as shown in Table 4. Along the Bangladesh coast, the rate of shoreline change is considerably faster. As a consequence, the vulnerability class intervals must be high. The vulnerability classes ranges found for the Bangladesh coast are higher than those used in most CVI studies due to rapid erosion and accretion.In Table 8 the average rate of shoreline change along transects has been western zone -5.19 m/yr, central zone -15.03 m/yr and eastern zone 3.06 m/yr. Table 5 compares the average rate of shoreline change along transects with the erosion vulnerability classification of Table 4, showing rapid erosion in the central zone and very highly vulnerable Figure 7. Similarly in western zone average rate of shoreline change is erosion and highly vulnerable. The average rate of shoreline change in the eastern zone is accretion and low vulnerable.

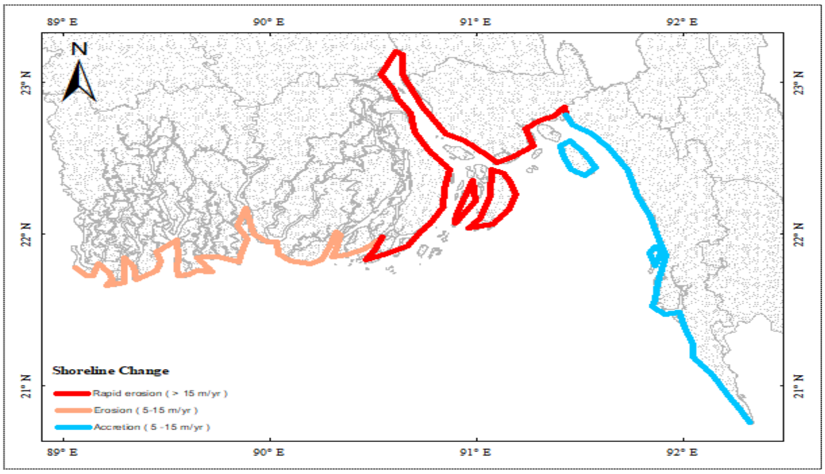

Figure 7: Erosion vulnerability of the coastal zone of Bangladesh

3.2.4 Combined Vulnerability Of The Coastal Zone Of Bangladesh

Sea level rise, tidal range and shoreline change have all been used to measure the vulnerability of Bangladesh's coastal region in this study. Different sections of the coastal zone have different levels of vulnerability in terms of various variables, but the formula used in the CVI calculation has shown a general pattern of vulnerability as show in Table 7. Vulnerability maps derived from various formulas have identified a common pattern of coast susceptibility. It has calculated the collective vulnerabilities of the coast to the combined listed variables Table 6.

Table 6: Ranking of Coastal Vulnerability Index (CVI) for coastal zone of Bangladesh

Variables	**Unit**	**CVI**		
		Western Zone	**Central Zone**	**Eastern Zone**
Sea-level rise		4	5	5,3
Tidal Range	m	5	4,3	1,2,4
Shoreline Change	m/yr	4	5	2

In Table 7, final CVI ranking has been done for western, central and eastern zone. From this CVI ranking, the effect of vulnerability will be understood in any zone. In CVI ranking, 5 are considered very high vulnerable and 1 is considered very low vulnerable. According to CVI ranking, western zone is high vulnerable. Central zone is very high vulnerable and eastern zone is low vulnerable as shown in Figure 8. This CVI can be used by coastal managers to concentrate attention on specific areas for a better management of the coast of Bangladesh.

Table 7: Final Coastal Vulnerability Index (CVI) ranking considering three variables for coastal zone of Bangladesh

	CVI		
Zone	**Western Zone**	**Central Zone**	**Eastern Zone**
Numbering	4	5	2

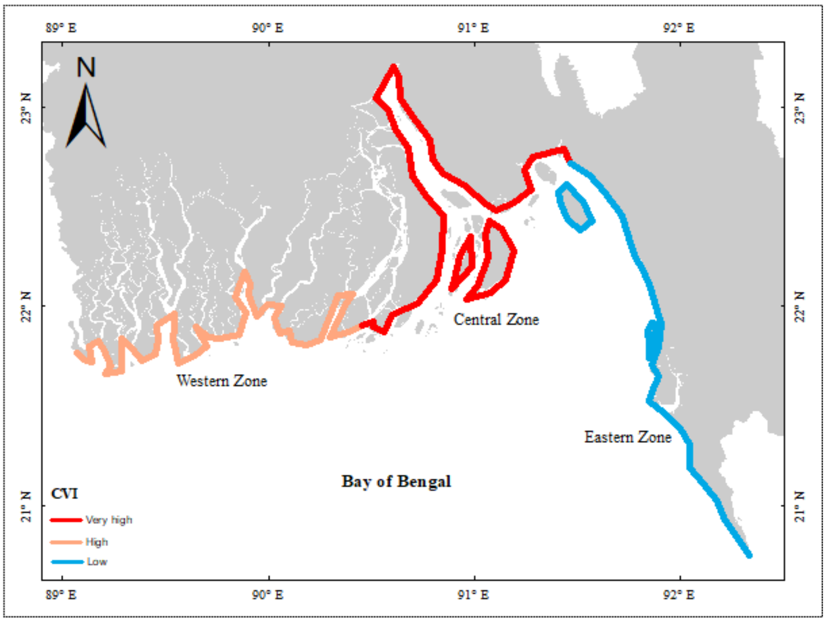

Figure 8: Coastal Vulnerability Index (CVI) of the Bangladesh coast on the basis of three variables

4. CONCLUSIONS

Bangladesh is especially vulnerable to increasing sea levels due to its location in the Bay of Bengal. The goal of this study was to analyze observed tidal water levels to illustrate the change in sea level along Bangladesh's coast. The short-term trend of tidal water level was analyzed in this study for a period of 30~35 years to assess the change in sea level rise along Bangladesh's coast. This extensive dataset of 30~35 years was created using available data that was consistent and of high quality.

The trend analyses were conducted using BIWTA and BWDB water level data. Along the coasts, 19 stations were chosen to cover three major geomorphological regions. The selection criteria for these stations are that each one represents regional differences in water level. However, accuracy checks revealed that seven of the initial 19 stations were discarded due to inconsistencies in the results. The yearly average water level was measured and plotted in a graph using the regular highest and lowest results. After plotting, the linear trend was determined using a simple linear regression method.

Analysis of tidal water of 30~35 years' shows rising trends of water level in the Ganges tidal floodplain of 4-8 mm/year. On the other hand, the trend is 2-10 mm/year in the Meghna Estuarine flood plain and 3-8 mm/year in the Chittagong coastal plain areas. The rate of change in sea level differed significantly along the coast, depending on the degree of exposure or distance of the station to the open sea. Land subsidence, sedimentation, wind circulation, polderization, and other local factors may have affected the regional estimate of SLR. With just a few exceptions, this study focused on the increasing trend of annual high, mean, and low tide water levels. In certain areas, the rate of rise in sea level appears to be surprisingly high, and this is only going to get worse with time. Policymakers and planners should use the results of this study to establish more practical and adaptable coastal management policies that reflect actual regional SLR trends.

This coastal vulnerability index is, to the best of our knowledge, the first attempt to chart the combined vulnerabilities of the Bangladesh coast. Other determinants of climate change adaptation capability, such as distribution resources, risk perception and understanding, and social capital, can be added to take it to the next level. Integration of coastal resources, coastal infrastructure, coastal hazard risk mitigation activities, and other development activities along the coast may result in a more meaningful index, allowing for a more integrated coastal zone management program within the country.

ACKNOWLEDGEMENTS

Thanks to Almighty Allah, for giving knowledge and strength to the authors to complete within the proper time. With due sincerity, the authors would like to express their heartiest gratitude and thankfulness to the respected Professor Dr. G M Jahid Hasan for his sympathetic and patient guidance and interest from the beginning of the work and moral support in many ways during the study period.

REFERENCES

Abuodha, P., and Woodroffe, C. D., (2010). "Assessing vulnerability to sea level rise using a coastal sensitivity index" a case study from southeast Australia, Journal of Coastal Conservation, 14(3), pp. 189-205.

Agrawala, S., Ota, T., Ahmed, A.U., Smoth, J., and Aalst, M.V., (2003). Development and Climate Change in Bangladesh: "Focus on Coastal Flooding and the Sundarbans", Organisation for Economic Cooperation and Development (OECD), Paris.

Begum, S., and Fleming, G., (1997). "Climate change and sea level rise in Bangladesh", part 1: Numerical simulation, Marine Geodesy, 20(1), pp. 33-53.

Brammer, H., (2014). "Bangladesh's dynamic coastal regions and sea-level rise", Climate Risk Management, 1, pp. 51-62.

Choudhury, A. M., Haque, M. A., and Quadir, D. A., (1997). "Consequences of global warming and sea level rise in Bangladesh", Marine Geodesy, 20(1), pp. 13-31.

Coelho, C., Silva, R.,Veloso-Gomes, F., and Pinto, F. T., (2006). "A vulnerability analysis approach for the Portuguese west coast", 5th International Conference on Simulation in Risk Analysis and Hazard Mitigation, Malta, Wit Press/Computational Mechanics Publications.

Diez, P. G., Perillo, G. M. E., and Piccolo, M. C., (2007). "Vulnerability to sea level rise on the coast of the Buenos aires province", Journal of Coastal Research, 23(1), pp. 119-126.

DOE, (1993). "Assessment of the vulnerability of coastal areas to sea level rise and other effects of global climate change", Pilot Study Bangladesh, Report Prepared by Department of Environment, Govt. of Bangladesh, Dhaka.

Dwarakish, G. S., Natesan, U., Asano, T., Kakinuma, T., Venkataramana, K., Pai, B. J., and Babita, M. K., (2009). "Coastal vulnerability assessment of the future sea level rise in Udupi coastal zone of Karnataka state", west coast of India, Ocean and Coastal Management, 52(9), pp. 467-478.

Gornitz, V., and Kanciruk, p., (1989). "Assessment of global coastal hazards from sea level rise", Sixth on Coastal and Ocean Management, Charleston, South Carolina, ASCE.

Gornitz, V., and White, T. W., (1991). "The global coastal hazards data base (ed.)", Future Climate Studies and Radio-Active Waste Disposal, Safety Studies, Norwich, England.

Gornitz, V. M., Beaty, T. W., and Daniels, R. C., (1997). "A coastal hazards data base for the U.S west coast", Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory.

Gornitz, V. M., Daniels, R. C., White, T.D., and Birdwell, K. R., (1994). "Vulnerability to sea level rise in the U.S. Southeast", Journal of Coastal Research, 12, pp. 327-338.

Hegde, A.V., and Reju, V. R., (2007). "Development of coastal vulnerability index for Mangalore coast", India, Journal of Coastal Research, 23(5), pp. 1106-1111.

IPCC, (2007). Climate Change Impacts, Adaptation and Vulnerability, Summary for Policymakers, Intergovernmental Panel on Climate Change.

Matin, N. and Hasan, G. M. J, (2021). "A quantitative analysis of shoreline changes along the coast of Bangladesh using remote sensing and GIS techniques", Journal of Coastal Consrevation, Catena, 201.

Nageswara, Rao, K., Subraelu, P., Venkateswara, Rao, T., Malini, B. H., Ratheesh, R., Bhattacharya, S., Rajawat, A., and Ajai, (2008). "Sea level rise and coastal vulnerability assessment of Andhra Pradesh coast", India through remote sensing and GIS, Journal of Coastal Consrevation, 12(4), pp. 195-207.

Ozyurt, G., and Ergin, A., (2010). "Improving coastal vulnerability to sea level rise" A new indicator-based methodology for decision makers, Journal of Coastal Research, 26(2), pp. 265-273.

Pendleton, E. A., Thieler, E. R., and Williams, S. J., (2010). "Importance of coastal change variables in determining vulnerability to sea level and lake level change, Journal of Coastal Research, 26(1), pp. 176-183.

Sawar, M. G. M., (2011), “Vulnerability assessment of the coast of Bangladesh using geographic information systems”, pp. 177-212.

Singh, O. P., Khan, T. M. A., Murty, T. S., and Rahman, M. S., (2001). “Sea level change along Bangladesh coast in relation to the southern oscillation phenomenon”, Marine Geodesy, 24(1), pp. 65-72.