EFFECTS OF SEA LEVEL RISE IN CHATTOGRAM CITY

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ABSTRACT

Bangladesh is likely to be one of the most vulnerable countries in the world to sea level rise. In order to evaluate the complex impacts of sea level rise, this study examines the particular situation of Chattogram City, which is the second-largest city in Bangladesh and an important economic center. To present a comprehensive picture of the effects, the study uses an interdisciplinary methodology that combines environmental and water science and social analysis. The environmental component focuses on the physical changes occurring in and around Chattogram due to rising sea levels. The study also looks at social justice problems because vulnerable groups are frequently impacted by sea level rise disproportionately. Linear regression and Sen slope estimator methods were used to analyse sea level rise trends in Chattogram City. Inundation maps spanning 10 years were generated using ArcGIS 10.8.2, enabling the calculation of inundated areas. Historical water level data analysis determined the inundation duration. The observed effects in these inundated areas were compared with collected data and adaptation measures were then suggested to mitigate potential damage. To conduct trend analysis, monthly water level data from 2015 to 2022 was collected from BWDB. In order to generate inundation maps, Landsat-8 images spanning from 2015 to 2022, with an interval of 16 days, were collected from USGS Earth Explorer. Linear regression and Sen's slope method reveal pronounced upward trends in sea level with slopes of 0.6 and 1.08 (Karnaphuli and Halda rivers) and 0.45 and 1.02 (Sen's slope method). The analysis of inundated areas in Chattogram City shows fluctuations over the years: 2015 (3.39%), 2016 (3.47%), 2017 (3.53%), 2018 (3.35%), 2019 (4.09%), 2020 (3.98%), 2021 (4.17%), and 2022 (4.63%), indicating varying levels of annual inundation. Overall, there has been an increase in the inundated area over this period, with a total increase of approximately 1.24%. Then adaptations for the identified effects were suggested in Chattogram City which include the construction of coastal embankments, elevation of land and implementation of rainwater harvesting techniques. A combined effort of the Bangladesh Government and Bangladesh's people is needed to reduce the effects of sea level rise not only in Chattogram City but all over the world. This study attempts to give stakeholders, researchers, and policymakers a thorough grasp of the issues raised by sea level rise in Chattogram City by integrating these points of view. The results offer significant contributions to the wider discussion on resilience methods and climate change adaptation for coastal cities worldwide.

Keywords: *Bangladesh, Coastal Zone, Linear regression, Sen slope, Sea-level Rise.*

1. INTRODUCTION

The impact of climate change, manifested in extreme heat, severe floods, and shifting weather patterns, has become a global concern. The melting of giant ice sheets in Greenland and Antarctica contributes to rising sea levels (KHRISTODAS et al., 2022), particularly affecting coastal regions like Chattogram in Bangladesh. Bangladesh, with a 720 km coastline along the Bay of Bengal, faces annual sea level rises of 2 to 5 millimeters (Bangladesh Meteorological Department). Chattogram, situated in the Ganges-Brahmaputra-Meghna River delta, is especially susceptible due to factors like sediment supply and subsidence (Brammer, 2014). Global sea levels are projected to rise by 0.26 to 0.77 meters by the century's end (IPCC, 2022). Regional considerations may exacerbate this in Chattogram, making it crucial to understand the local impact. The Intergovernmental Panel on Climate Change (IPCC) predicts a rise in average global temperatures and accelerated sea level increases (IPCC, 2022). Bangladesh's coastal areas, particularly Chattogram, face significant threats. Sea level rise poses risks of inundation, erosion, and damage to coastal areas. "Inundation maps" and analysis of sea level rise trends provide insights into potential damage and impacts (Leon et al., 2014). Bangladesh faces the dual challenge of adaptation and mitigation. Fishermen and farmers, the majority of the coastal population, need specific attention in developing effective strategies. Ignoring sea level rise in development plans could jeopardize sustainability, impacting Bangladesh's economy, environment, and security. Understanding the trends and consequences of sea level rise is essential for devising sustainable development plans.

This study aims to highlight potential effects and recommend strategies for integrating sea level rise considerations into Bangladesh's development activities and investigate Bangladesh's sea level increase rate and the trend, particularly focusing on a potential rise of up to one meter. Examine the extent of inundation in Chattogram City from 2015 to 2022, highlighting incremental changes in water levels. Analyze the detention time of seawater in coastal land and assess seawater infiltration in the surrounding areas. Explore the potential effects of saline water on inundated areas, including impacts on agriculture, landmass, settlements, the salt industry, tourism and the overall environment. Investigate local and global strategies for adapting and mitigating the consequences of sea level rise, assessing Bangladesh's preparedness for future events. The study aims to provide comprehensive insights into water level rise in Chattogram City, addressing these key questions. Investigate long-term data to understand the trends of sea level rise in Chattogram City. Analyze the potential effects of sea level rise on Chattogram City, focusing on damage assessment. Propose adaptations to mitigate and prevent potential damages in Chattogram City.

Addressing the vulnerability of Chattogram City to flooding, erosion, and salinization, the study holds paramount importance as a densely populated economic center. Specifically, this study pertains to Chattogram City, with the area under consideration being Chattogram City Corporation. Utilize historical sea level data from Bangladesh Water Development Board (BWDB) for analysis, employing statistical methods to identify trends. Employ ArcGIS 10.8.2 to map inundated areas using Landsat-8 images from USGS (Earth Explorer), assessing the potential extent of damage. Conclude by suggesting proper adaptations to address the identified effects. Acknowledge the study's assumptions regarding a specific time frame and sea level rise scenario, recognizing potential uncertainties in future projections.

2. METHODOLOGY

A comprehensive methodology aligning with the study's objectives was devised, commencing with a review of literature, evaluation of existing models for sea level change estimation, and analysis of observed trends. Recognizing knowledge gaps, the research examined global and Bangladeshi contexts related to sea level rise.

The linear regression model was chosen as the number of datasets were moderately large increasing the accuracy of the trend, while the Sen's Slope estimator is more robust to outliers due to its non-parametric nature.

2.1 Trend Analysis of the Observed Sea Level

Table 1: Selected Stations for Trend Analysis of Chattogram City

SL No.	Organiz-ation	Station Name	Station ID	River	First date of collected data	Last date of collected data
1	BWDB	Kalurghat	SW152.2	Karnaphuli	01-JAN-13	31-DEC-22
2	BWDB	Enayethat	SW121	Halda	01-JAN-13	31-DEC-22

Tide gauges and satellite altimetry were utilized globally for monitoring sea level changes. Selected water level stations in Chattogram City were subjected to trend analysis, addressing consistency, serial auto-correlation, and identification of observed trends. Linear regression, Sen's slope estimator, and the Mann-Kendall test were employed to analyze sea level trends.

To estimate the trend of sea level using Sen's slope estimation, the sea level data are first sorted in chronological order. Then, the differences between each pair of data points are calculated and ranked in ascending order. The slope for each pair of data may be calculated as follows:

$$Q_k = \frac{(x_j - x_i)}{(t_j - t_i)} \tag{1}$$

Where, k = [1, n(n − 1)/2], i = [1, n − 1], j = [2, n]. X_j and X_i are the data values at time t_j and t_i, respectively. Sen's slope estimator can be calculated as follows:

$$Q_m = \begin{cases} Q_{\left[\frac{n+1}{2}\right]} & ; if\ n\ is\ odd \\ \frac{Q_{n/2} + Q_{(n+2)/2}}{2} & ; if\ ni\ even \end{cases} \tag{2}$$

The Q_m sign reflects the data trend, while its value indicates the steepness of the trend. The median of these ranked differences is the median slope, which represents the trend of the sea level over the study period.

Analyzing all potential measurement pairs in the data set yields the Mann-Kendall S statistic. S is increased by one if the subsequent value has a larger magnitude than the earlier one. On the opposite hand, S is reduced by one if the subsequent value is smaller in magnitude than the original sample.

The Mann–Kendall statistic parameter, S, is computed as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(X_j - X_i) \tag{3}$$

Where, X_i and X_j are random variables (divided the given time series X into two variable sets, as X_1, X_2, . . . , X_i, and X_{i+1}, X_{i+2}, . . . , X_j).

$$Sign(X_j - X_i) = \begin{cases} 1\ if\ X_j - X_i > 0 \\ 0\ if\ X_j - X_i = 0 \\ -1\ if\ X_j - X_i < 0 \end{cases} \tag{4}$$

The variance of S, VAR(S), is given by

$$VAR(S) = \frac{n(n-1)(2n+5) - \sum_{p=1}^{m} t_p(t_p - 1)(2t_p + 5)}{18} \tag{5}$$

The standard test statistic Zs is calculated as follows:

$$Z_s = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} & for\ S > 0 \\ 0 & for\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} & for\ S < 0 \end{cases} \tag{6}$$

Where tp is the frequency of the pth value, m is the total amount of individual values (without duplicates), and n is the number of data points. The null hypothesis is rejected and the trend is significant if |Zs| is greater than the corresponding Z/2, which represents the chosen significance level (= 10% at the 90% confidence level with Z(0.05) = 1.65; = 5% at the 95% confidence level with Z(0.025) = 1.96; = 1% at the 99% confidence level with Z(0.005) = 2.58. A rising trend is indicated by a positive Zs value, whereas a falling trend is shown by a negative Zs value. Inundation maps for the last 8 years were created using ArcGIS 10.8.2 with Landsat imagery. Classification and validation processes ensured accurate identification of inundated areas. The extent of inundated areas and their effects were calculated using various data sources, including BWDB maps, soil salinity data, IPCC reports, and agricultural statistics.

2.2 Identifying the Effects of Damage in Chattogram City

Several data are available from different sources to determine the effects of damage. From those- Inundation maps of Chattogram City were created using the Landsat images and validated by the maps available from BWDB. Another parameter to find out the effect of damage is the salinity of soil and water. Impact on landmass and settlement is also a parameter to find out the possible effects.

Table 2: List of Acquired Data to Study the Possible Effects of Damage on Chattogram City.

SL No	Purpose	Required data	Data Source
01	Determination of damage area and flood depth	Inundation Map	Bangladesh Water Development Board (BWDB)
		Landsat Image	USGS (United States Geographical Survey) Earth Explorer
02	Impacts of salinity	Soil Salinity data	SRDI (Soil Resource Development Institute)
03	Impacts on landmass and settlement	Total area vs potential land loss by 1-m SLR	Intergovernmental Panel of Climate Change (IPCC)
04	Impacts on landmass and settlement	Total population vs 1-m SLR-affected population	Intergovernmental Panel of Climate Change (IPCC)
05	Impacts on agriculture	Distribution of major cropped areas	Bangladesh Bureau of Statistics
		Amount of Rabi and Kharif production	Chittagong Metropolitan Agricultural office, Patenga
06	Reduction of agricultural land	Loss of cropland as sea level rises	Flood and Agriculture Organization of the United Nations
07	Coastal erosion	The recession of the eastern coastline	(Yang et al., 2015)

2.3 Study Area

Chattogram, part of the Chattogram division, is characterized by diverse topography, including hills, sea, valleys, and forests. Geographical location: 20°35' to 22°59' north latitude, 91°27' to 92°22' east longitude. Geographical boundaries: Bounded by Feni district, Tripura State of India, Cox's Bazar district, Bandarban, Rangamati, Khagrachari districts, Noakhali district, and Bay of Bengal.

Total land area: 5,283 square kilometers.
Major rivers: Karnaphuli, Halda, Sangu.

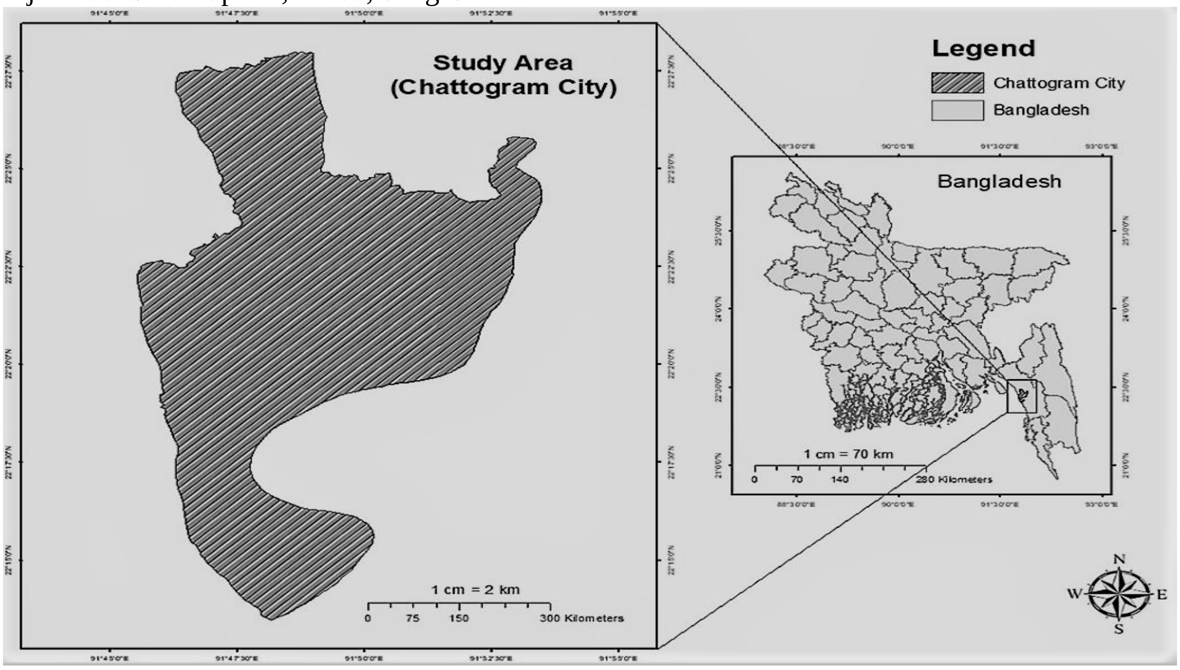


Figure 1: Chattogram City Map

High vulnerability to flooding and sea level rise due to its geographic features. Chattogram's unique characteristics and vulnerability make it an apt focus for regional adaptation planning, extending insights from this study to potentially benefit the entire country.

3. RESULTS & DISCUSSIONS

3.1 Trend of Sea Level

Trend analysis of average sea level with respect to following period given below:

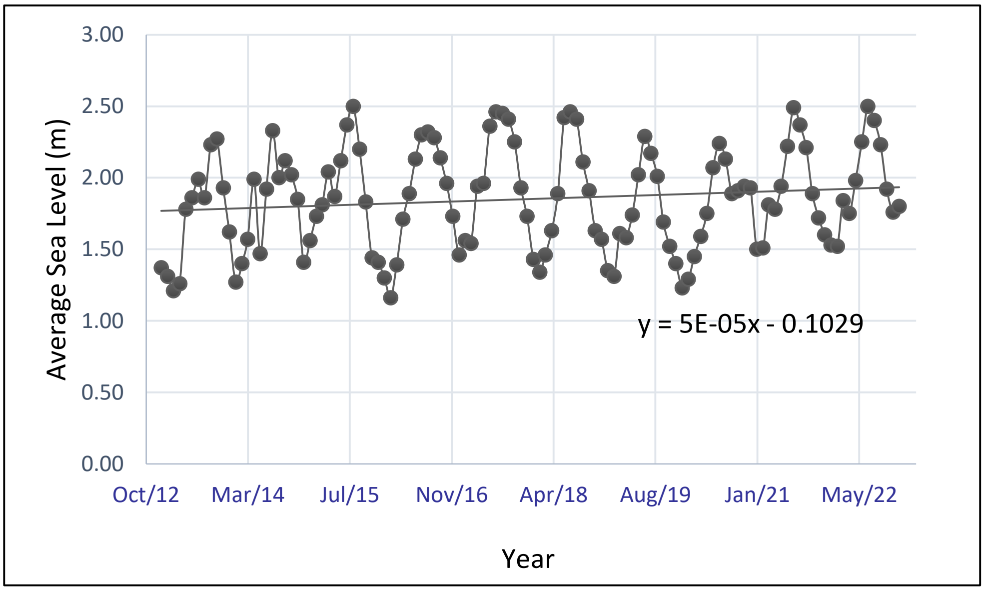


Figure 2: Trend of sea level at Kalurghat station in different months through 2013-2022.

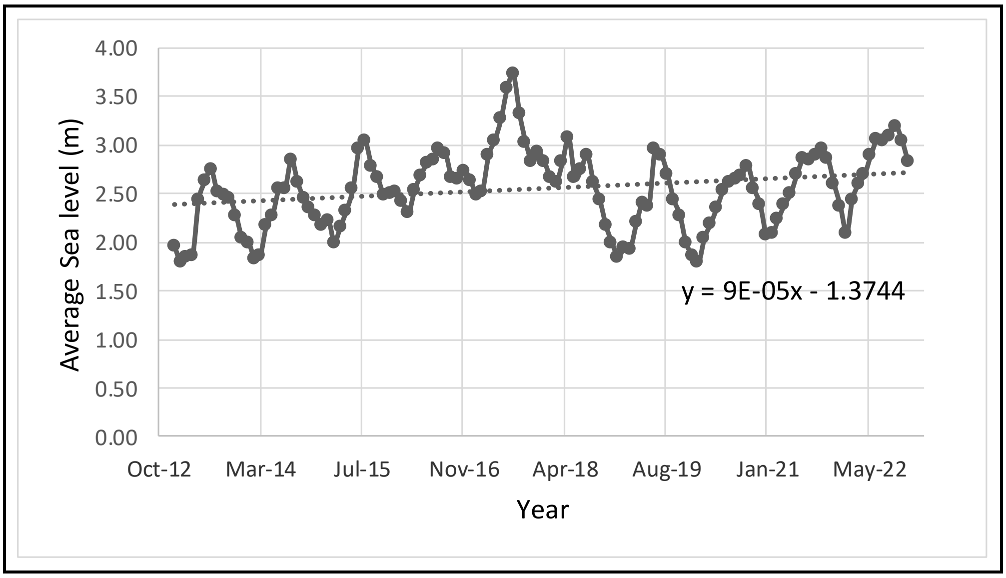


Figure **Error! No text of specified style in document.**: Trend of sea level at Enayetghat station in different months through 2013-2022.

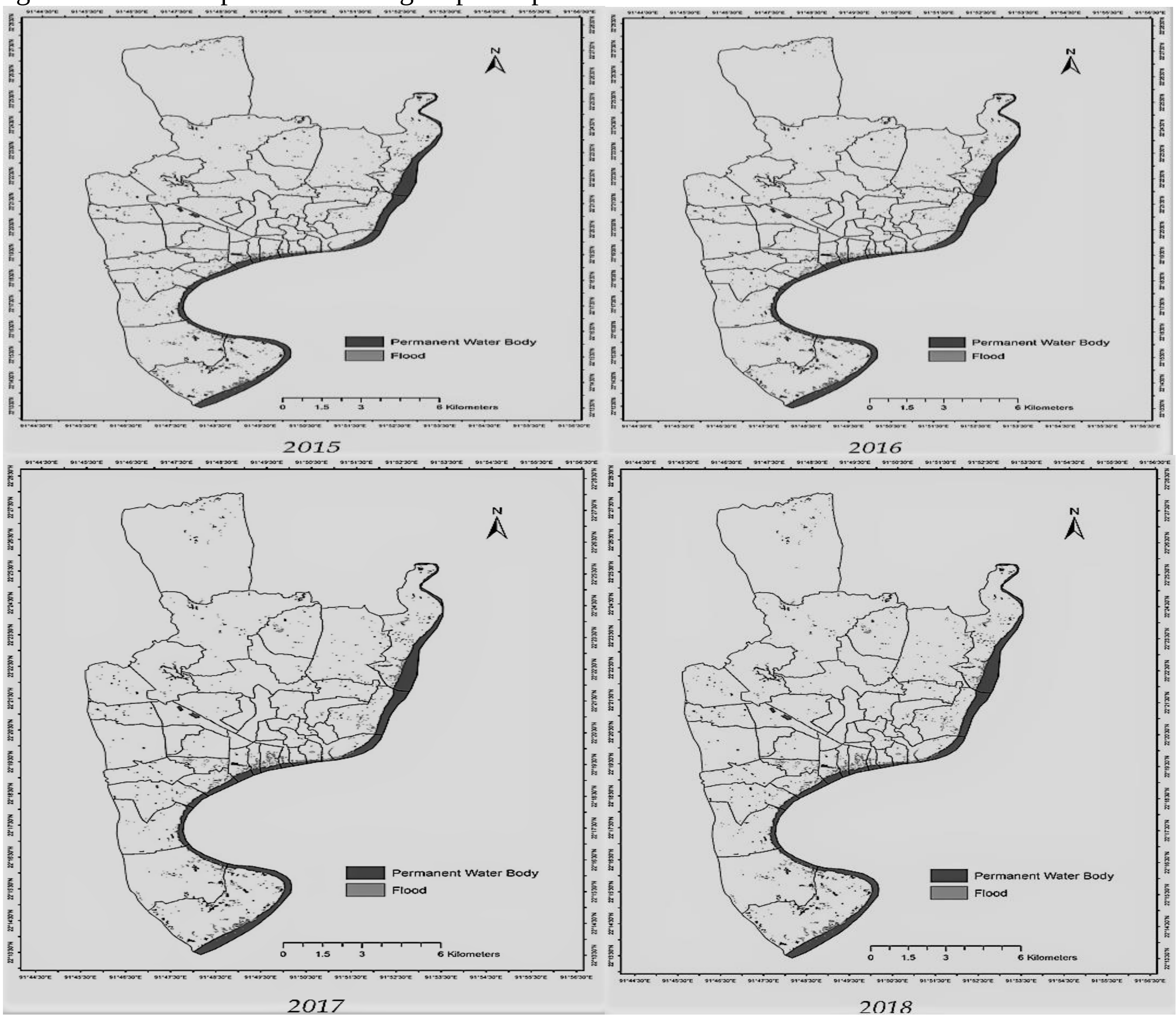
Table 3: Trend analysis of water level data

Station ID	Location	Analysis Period	Trend based on Linear Regression slope (mm/year)	Trend based on Sen's slope (mm/year)	Value of Z	Significance level
SW152.2	Karnaphuly	2013-2022	0.6	0.45	2.17	Significant at 95%
SW121	Halda	2013-2022	1.08	1.02	1.98	Significant at 97%

The results obtained from the linear regression method suggest a positive trend in sea level over the analyzed period. A slope of 0.6 indicates a relatively moderate increase, while a slope of 1.08 suggests a more pronounced upward trend. In contrast, the Sen's slope method provides a robust estimation of the trend in time series data by considering all possible pairs of data points. The calculated slopes of 0.45 and 1.02 from this method further support the presence of an upward trend in sea level, albeit with slightly lower values compared to the linear regression analysis.

3.2 Inundated Area

Chattogram, located in southeastern Bangladesh, faces recurrent flooding due to its deltaic geography and low-lying topography, especially during the monsoon season. Utilizing Landsat-8 images spanning the last eight years, inundation maps were generated using ArcGIS 10.8.2 and validated against BWDB maps. The resulting maps are presented below.



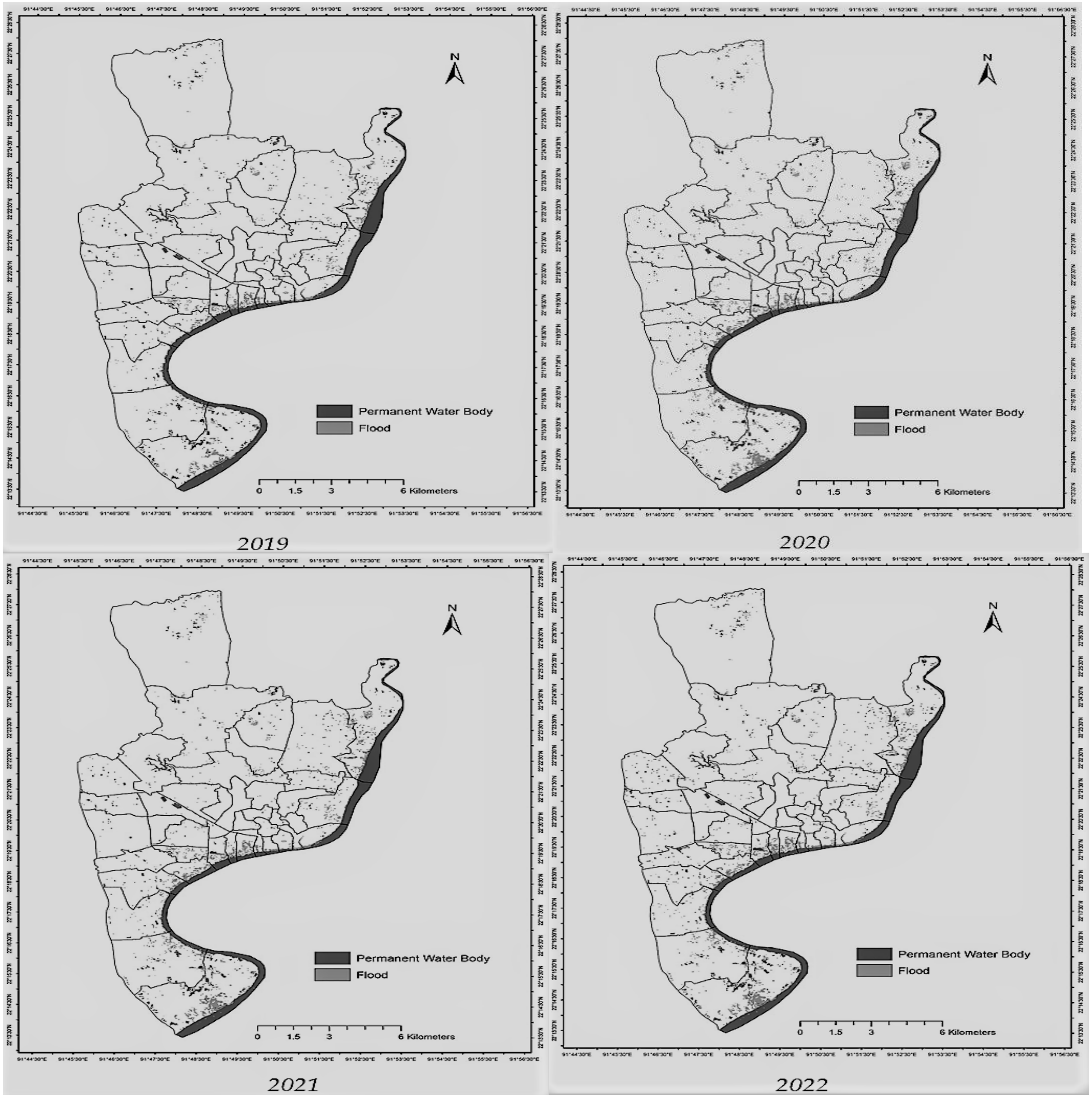
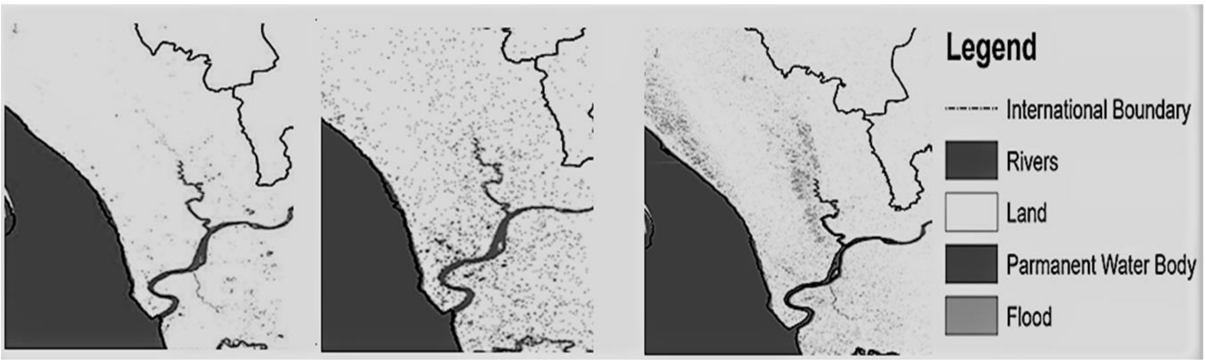


Figure 4: Inundation Maps (2015 to 2022)



(a) (b) (c)

Figure 5: Inundation maps prepared by Flood and Forecasting warning center (Chattogram area) (a) Map of 2020, (b) 2021, (c) 2022 according to the flood level. (Source: BWDB)

An inundated area refers to a region or locality that has been flooded or submerged by water. The total inundated areas for the different four years are given below:

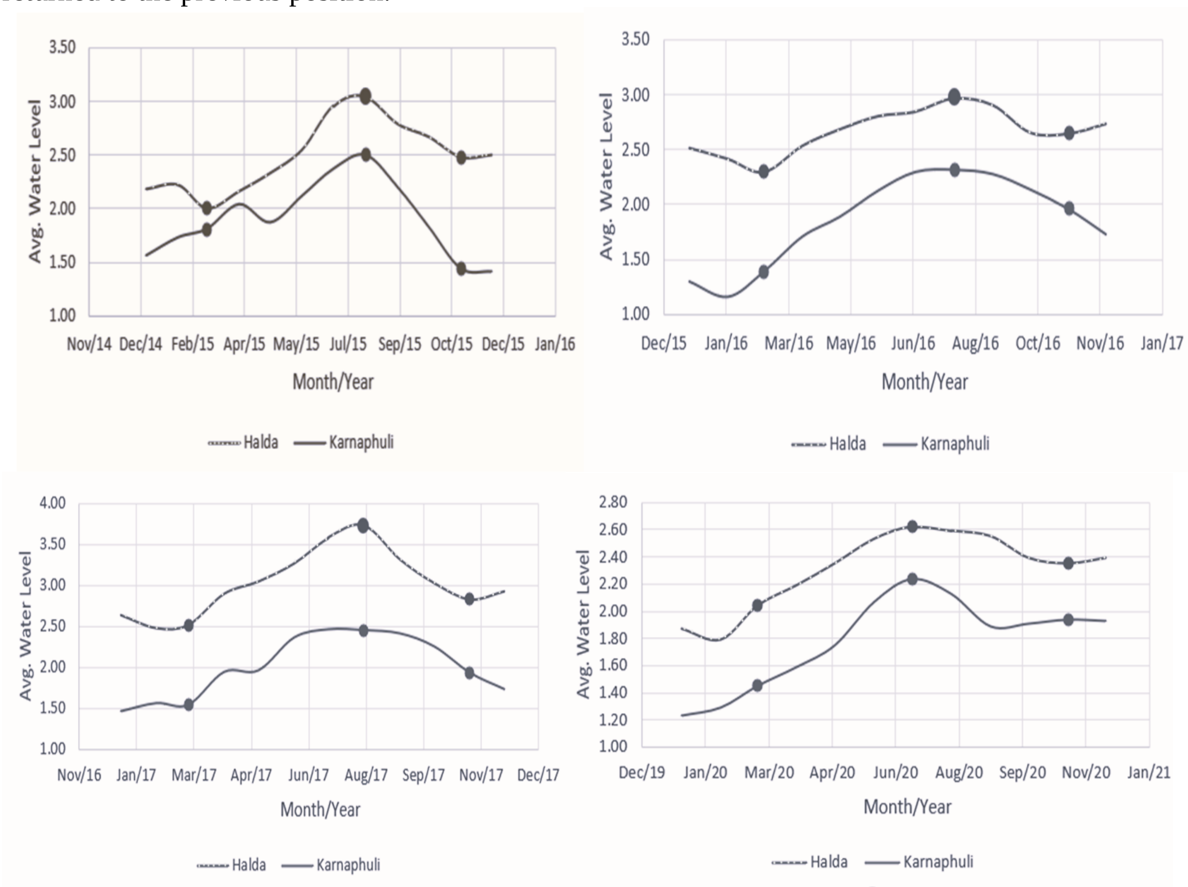
Table 4: Inundation area of Chattogram City for the last eight years

Year	Inundated area (km^2)
2015	5.6987
2016	5.8256
2017	5.9245
2018	6.2514
2019	6.8646
2020	6.6825
2021	7.0068
2022	7.7841

The inundation maps reveal critical insights into the spatial and temporal patterns of flooding in Chattogram City. The analysis indicates a notable increase in flood-prone areas over the 8-year period, with several neighborhoods experiencing repeated inundation events. The inundated area largely increased from 5.6987 in 2015 to 7.7841 in 2022.

3.3 Inundation Duration

For the year 2022, the water level for both rivers was lowest in February. And subsequently were highest between July and September. After that during November and December, the water level returned to the previous position.



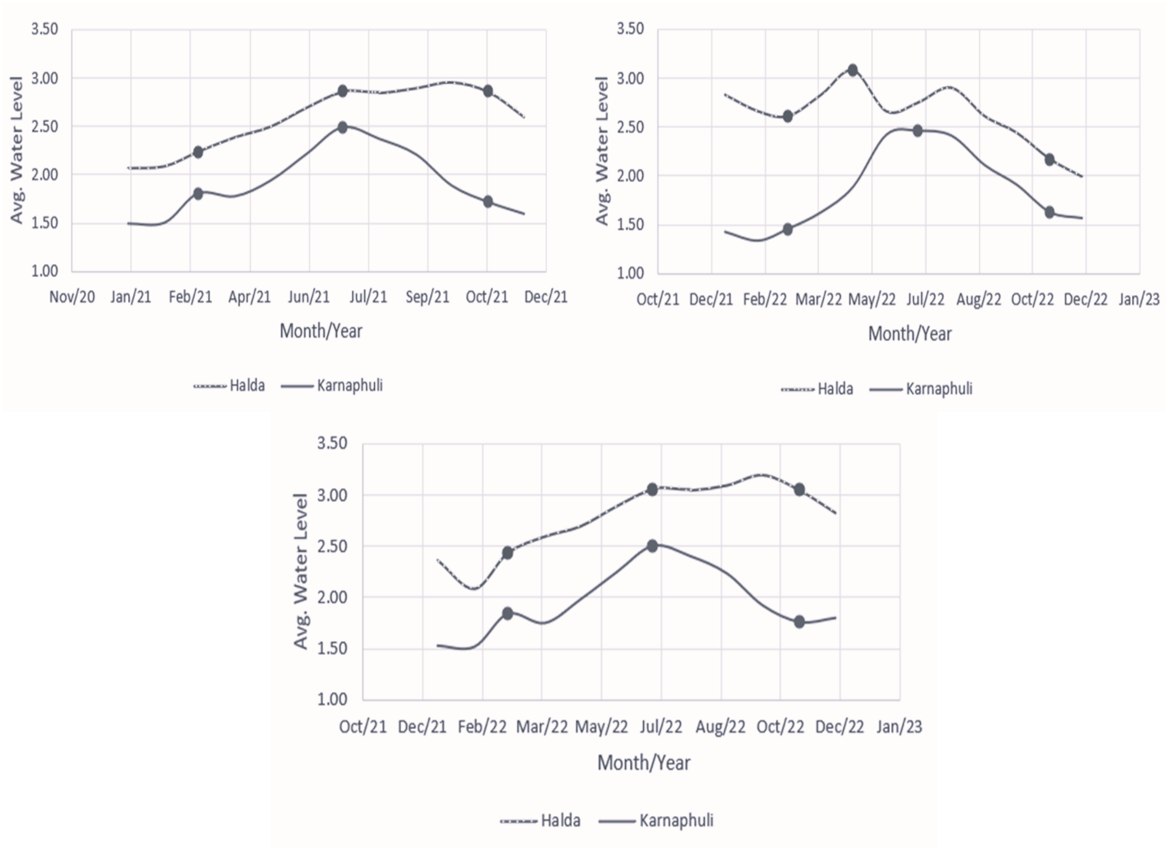


Figure 6: Inundation Duration (2015 to 2022)

3.4 Identification of Effects

3.4.1 Impacts of Salinity

Sea level rise can have a strong impact on soil and water salinity in coastal areas, which can have far-reaching effects on agriculture, ecosystems, and human populations. According to the Soil Resource Development Institute (SRDI, 2010), irregular rainfall, upstream withdrawal of fresh river water, improper management of many sluice gates, the introduction of brackish water from shrimp farming, the regularity of saline tidal flooding in exposed areas, and the capillary rise in soluble salts are expected to be the main causes of increased soil salinity in the top soils of the coastal region. The increasing affected area of soil salinity is 29.7% in just 36 years.

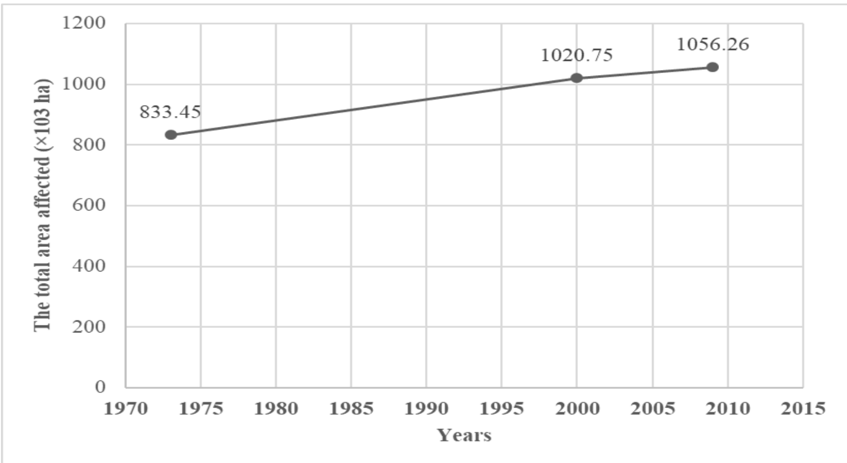


Figure 7: Total Area Affected by Soil Salinity ($\times 10^3$ ha) in coastal regions of Bangladesh.

According to a report of The Business Standard, (The Business Standard | BENEATH THE SURFACE, n.d.) human suffer from the Halda water's excessive salinity, and the lack of operation of the Chattogram WASA treatment plant. The tolerable salinity level in drinking water is 150-600mg per liter. Salinity at Mohra water treatment plant of Halda is 1700mg per liter. The main cause of high salinity is salty sea water entering Halda during high tide. So, water production decreased by 1.5cr liters due to the closing of Mohra treatment plant.

3.4.2 Impacts on Landmass and Settlement

In Bangladesh, especially the coastal zone of Chattogram City already experienced significant land loss due to coastal erosion and rising sea levels. A study by the (Islam et al., n.d.) estimated that, by 2050, 12.5% of the land area of Chattogram City may be inundated by sea level rise. Additionally, the study predicted that 16% of Chattogram's land area might be underwater by 2100 if the sea level increases by 1 meter.

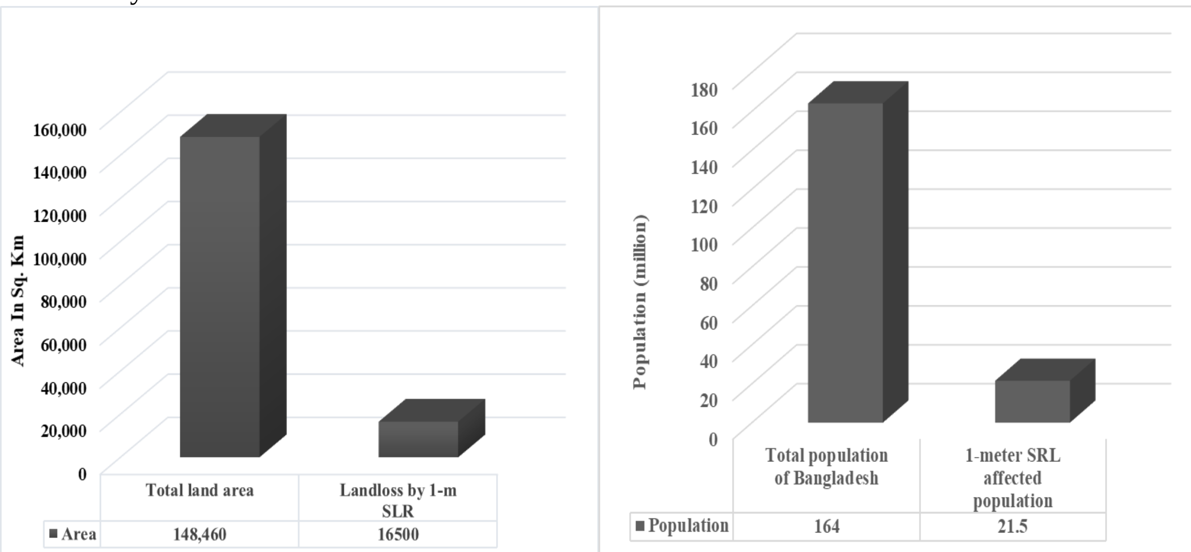


Figure 8: Total Area vs Potential Land Loss by 1m Sea Level Rise and Total Population vs 1-m Sea Level Rise Affected Population(“Cities and Settlements by the Sea,” 2023)

3.4.3 The Backwater Effects

The backwater effect is the term used to describe how sea level rise causes water levels to rise and water flow velocity to decrease in rivers and estuaries. Sea-level rise in Chattogram may result in higher water levels in the Karnaphuli River and its tributaries, which may result in floods and erosion in low-lying communities along the river banks.

3.4.4 Agriculture

There are 19 districts in total roughly 47,203 km^2 in the coastal region of Bangladesh, with Chattogram being one of them. The majority of the coastal areas and related Chattogram divisions are located less than one meter above sea level, where saline water intrusion is frequent. These areas are expected to become swamped and unsuitable for food cultivation in the next 50 years due to sea level rise. The Intergovernmental Panel on Climate Change estimates that Bangladesh would lose the most arable land as a result of increasing sea levels.

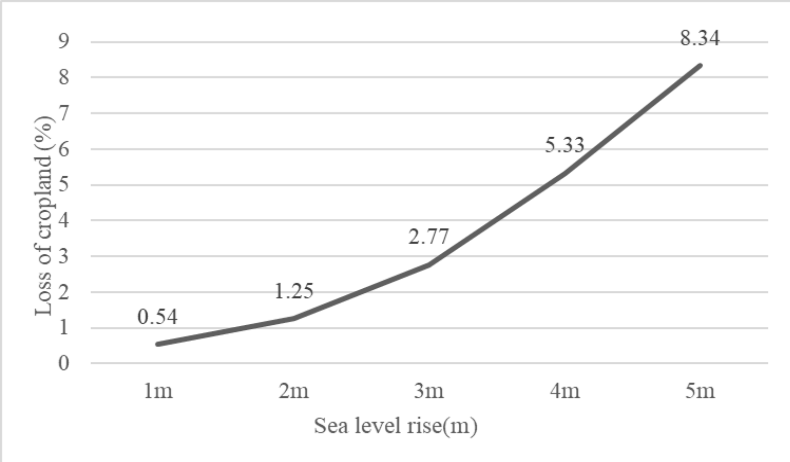


Figure 9: Cropland loss in Bangladesh (Roy et al., 2022) and (FAO, 2022)

3.4.5 Effect in Tourism:

Sand beaches make up a sizable portion of Bangladesh's coastline and draw visitors. Patenga Beach in Chattogram City is one of the most popular tourist destinations in the nation. Patenga, Chittagong Beach, which is situated in the coastal zone and was listed as one of the top 18 most lucrative tourist destinations by Bangladesh Parjatan Corporation, is extremely vulnerable to SLR destruction. In Bangladesh, particularly Patenga in Chattogram, strong tides and wave heights, strong wind waves and currents during the rainy season, and elevated river flow (central coastline zone) are the main sources of coastal erosion. The rate of coastal erosion brought on by SLR is not precisely known. However, a lot of academics made estimates of how SLR would affect erosions. According to ("Cities and Settlements by the Sea," 2023), Bangladesh's eastern coastline would experience an average recession of nearly 87 times the SLR.

4. CONCLUSIONS

This thesis examines the escalating sea level rise in Chattogram City, analysing trends, predicting damages, and proposing adaptations. The findings highlight the city's vulnerability, emphasizing the pressing need for proactive measures to counteract the adverse effects.

The analysis conducted in this study clearly demonstrated an upward trend in sea level rise over the last ten years. Sea level rise trends in Chattogram City, determined by linear regression and Sen's slope method, demonstrate pronounced upward trends with slopes of 0.6 and 1.08 (Karnaphuli and Halda rivers) and 0.45 and 1.02 (Sen's slope method). Analysis of inundated areas reveals fluctuations in annual inundation percentages over the years: 2015 (3.39%), 2016 (3.47%), 2017 (3.53%), 2018 (3.35%), 2019 (4.09%), 2020 (3.98%), 2021 (4.17%), and 2022 (4.63%). Overall, the data indicates an overall increase in the inundated area, with a total rise of approximately 1.24% during last eight years. This finding indicates a significant threat to Chattogram City and its vulnerable coastal areas. The effects of sea level rise were observed in various aspects, including infrastructure damage, increased flooding, saltwater intrusion, and displacement of local communities, effects on agriculture, health issues. These findings underscore the pressing need for immediate action to protect the city and its inhabitants.

In conclusion, this thesis has provided significant insights into the effects of sea level rise in Chattogram City, highlighting the urgent need for adaptation measures. By understanding the increasing trend of sea level rise and its associated damages, policymakers and stakeholders can take proactive steps to safeguard the city and its inhabitants from the adverse effects of climate change. Further research in this field can enhance our understanding and contribute to more effective long-term strategies for resilience and sustainability.

Based on the outcomes of this research, several recommendations can be made for further studies in this field. Long-term monitoring and modeling studies can provide valuable insights into the future trajectory of sea level rise and aid in the formulation of proactive adaptation strategies. Future studies can explore the potential of nature-based solutions, such as mangrove restoration and wetland conservation, in mitigating the impacts of sea level rise. It would be beneficial to conduct an in-depth analysis of the economic and social implications of sea level rise in Chattogram City. Understanding the broader socio-economic consequences can help policymakers allocate resources more effectively.

5. FUTURE RECOMMENDATIONS

Although Sen's Slope Estimator provides robustness against outliers and Linear Regression provides simplicity and interpretability for sea level trend research, these techniques may not be able to fully capture the complex changes and highly non-linear patterns normally present in sea level data. The outliers removed during trend analysis were mostly collected data during Covid-19 lockdown period, so there may be uncertainity in these specific months data. The authors had to rely on statistics provided by official authorities of Bangladesh on effects in different sectors.

To address these limitations, the authors recommend Empirical Mode Decomposition (EMD) method for future validation attempts in order to alleviate these constraints. Because of its ability to capture complex patterns, resilience to outliers, and flexibility in dealing with non-linearity, EMD is a possible substitute. There are no separate studies on backwater effects in rivers of Chattogram due to sea level rise and the authors recommend further studies on this to validate the presumption.

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