International Journal of Research
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 07 Issue 08
August 2020

Analysis of Shoreline Change and the Problem of Saltwater Intrusion: A Case Study on Sagar Island and its South-Eastern Part, West Bengal, India

Shilpa Saha[1] & Rakhi Das[2]*

[1,2]Research Scholar, Department of Geography, The University of Burdwan

[*]Corresponding Author: shilpasaha97@gmail.com

Abstract

The problem of coastal erosion is increasing at a large scale due to the changing climatic and other environmental factors. The northern and south-eastern part of the Sagar Island, India shows the signs of accretion after 1980. On the other hand, the southern coast of the region came under the impact of severe erosion. Multitemporal satellite data have been used for analysing the change of shoreline along the coast of Sagar Island. The areal change of the Sagar Island shows that 10.78 sq.km. of the land has been eroded whereas deposition or accretion has taken place on 8.16 sq.km. of land during 1980-2017. Due to the inherent quality of land and breaching of the embankment, the problem of coastal erosion became acute in the region. It leads to further degeneration of the land causing intrusion of saltwater in the southeast part of the island. Soil samples have been collected to observe the change in the salinity levels around the region. In the village of Boatkhali, due to the problem of saltwater intrusion into the agricultural fields and decreasing productivity of the land, these lands have been converted into fishing grounds. Most of the inhabitants of the region are living with a low standard of living and are unsatisfied with the government measures of protecting land from the impact of high energy waves.

Keywords: *Coastal erosion; Sagar Island; Boatkhali; Embankment; Saltwater intrusion.*

1. Introduction

Coastal system is a dynamic interaction between coastal morphology [1], the action of waves [2], tides and currents [3] and sediments movements [4]. A variety of human activities depends on the available natural resources [5] of the diversified coastal habitats [6]. The resulting inundation from rising sea levels [7] will heavily impact the low-lying areas [8] of the world. With the phenomenon of Global Warming and Climate Change [9], the coasts of the world are under severe threat [10]. The Hugli estuary is acting as a sediment sink and is largely offsetting the effects of an accelerated sea level rise in terms of land loss [11]. The estuarine island emerges, accrete and dissipate due to sediment reworking in a high energy cyclone dominated macro tidal environment without any obvious sea level change [11]. Surface air temperature over the Bay of Bengal is rising at the rate of 0.019^{o}C per year which is correlated with the rate of relative sea level rise of 3.14mm per year, near Sagar Island [12]. Mangrove forest cover is predicted to diminish further along with degradation of the existing species combination [12]. Around Sagar Island, coastal erosion is increasing day by day [13]. It is observed that around north-northeast, east-southeast, south, west, northwest parts the process of erosion is dominant and in north, northeast, southeast and west the parts accretion process is dominant. It indicates that both the processes are operating side by side [14]. The north-eastern, south-eastern and south-western faces of Sagar Island are subjected to severe erosion [15]. Major causes of coastal erosion are the reduction in fluvial supply for a long period, wave, tidal and cyclonic activities, sea level rise and land subsidence along with human interference [15]. Multitemporal satellite data analysed for change detection studies showed that from 1998 to 1999, the Sagar Island had undergone erosion of 3.26 sq.km and the amount of accretion was 0.08 sq.km. [16]. Sagar Island was largely affected by a huge cyclone in 2008 during which 1300 families became homeless in the Shibpur-Boatkhali area [17]. The embankments built in line with the river and Bay-of Bengal are the most affected ones. In 2008 about 5 km of the embankment was totally broken by coastal flooding at Boatkhali because the construction on the Bay-of Bengal is very weak [17]. Continuous erosion and land loss change the characteristics of the land and decrease productivity [18]. Salinity remains increases rapidly, mangroves are degraded and sand deposited in the south-eastern part of Sagar Island [18]. Around south-eastern part of the island the coastal erosion results in saltwater intrusion [19] in the inland areas. The intrusion of saline water results in the changes of the productive capacity of the lands rendering the fertile lands into barren lands. With due time the agricultural lands have been converted into fishing

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 07 Issue 08
August 2020

grounds. But the solution to the growing problem is yet to be derived. As nature plays its role in changing the landscape, the natural process of building land [20] should not be disturbed by human intervention.

2. Objectives

The major objectives of the study are-

- To analyze the factors contributing to coastal erosion in Sagar Island.
- To measure the amount of erosion and deposition that occurred in Sagar Island.
- To assess the shoreline change in Sagar Island.
- To record the extent of saltwater intrusion in the south-eastern part of Sagar Island around the Boatkhali region.
- To delineate the changes in land use and land cover pattern due to erosional activity in the Boatkhali region.
- To provide mitigation measures and solutions for existing issues and problems.

3. Study Area

Sagar Island is the western most island of the Ganges-Brahmaputra Delta [21]. The latitudinal extension of Sagar Island is 21°37' N to 21°52'N and the longitudinal extension is 88°2'E to 88°10'E [22]. Sagar Island lies on the continental shelf of the Bay of Bengal. The island is severally encountered by a major tidal creek. The Hooghly River marks the northern and western boundary of the island. Bartala River locally known as Muriganga forms the eastern boundary of Sagar Island with several subsidiary channels or creeks and loses itself in the Bay of Bengal near the Dablat region. The elevation of the land is 6.5 meters from the mean sea level [22]. The land comprises of agricultural land, fishing grounds, wetlands and mangrove plantations in some areas along with growing human settlements. Primarily the island is built by silt and clay [15]. Clay soil occurs in swamps and alluvial lakes. The length and breadth of the Sagar Island is 26 km and 12 km respectively. The total geographical area was 285.40 sq. km. in 1951 [23]. It decreases to 235 sq. km in 2015 [18]. Sagar Island comes under the jurisdiction of the South 24 Parganas district of West Bengal, India [24]. Sagar Island consisted of nine Gram Panchayats with 43 mouzas. Boatkhali village is located in the south-southeast corner of the Sagar Island. Sagar Island comes under the zone of tropical warm and humid climate. The region is influenced by seasonal variation of monsoon winds and maritime actions of the Bay of Bengal. Sundarban is the largest mangrove ecosystems in the world. The main species of mangrove found here is Heriteria fomes locally known as Sundari.

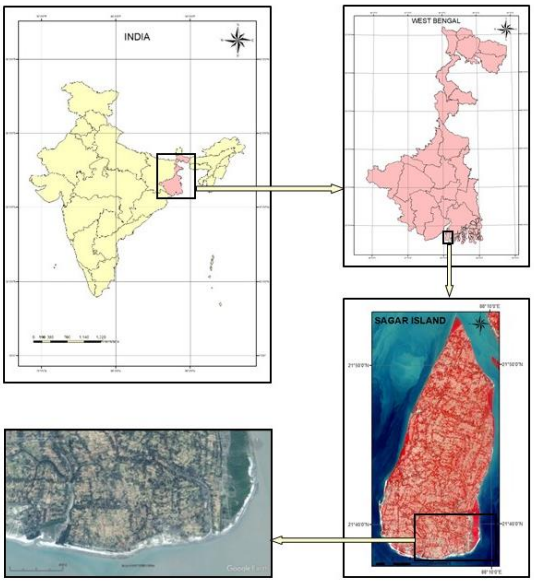


Fig.1. Study Area

4. Database and Methodology

For the purpose of our study, we have reviewed and analyzed secondary data, information and literature that is available in the public domain. Satellite images of different years were collected. Google Earth images have also been analysed for assessing the landscape change in the region. Processing and analysis of the collected information have been done using remote sensing software i.e., ArcGIS v10.3.1, ERDAS Imagine v2014 and Geomatica v2012.

Table 1: Characteristics of the Satellite Data Used

Spacecraft ID	Sensor ID	Date of Acquisition	Projection	Path/Row	No. of Bands	Spatial Resolution (m)
Landsat 3	MSS	16 Jan, 1980	UTM 45	148/045	4	30
Landsat 5	TM	30Jan, 1990	UTM 45	138/045	7	30
Landsat 7	ETM	17 Nov, 2000	UTM 45	138/045	8	30
Landsat 5	TM	6 Oct, 2010	UTM 45	138/045	7	30
Landsat 8	OLI_TIRS	14 Apr, 2017	UTM 45	138/045	11	30

Source: www.usgsearthexplorer.gov.in

Field Survey: Soil samples were collected from randomly selected points from Boatkhali village. Laboratory analysis of the soil samples was done using Salinity Meter or Conductivity Meter. Primary data and information were gathered from interviews and questionnaire survey with residents of the village to identify the impacts of saltwater intrusion. Samples have been selected using a

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 07 Issue 08
August 2020

random sampling technique. The total number of samples is twenty-five.

5. Results and Discussion

5.1. Causes of Coastal Erosion

Coastal erosion is a natural hazard occurring along the coasts over the world. Several factors are responsible for the erosional activity along the coasts. The main causes of coastal erosion in Sagar Island are found as follows-

- Severe bank erosion in the north and south-eastern parts of the island.
- Wave erosion in the south-eastern and south-western part of the island.
- High flood velocity during the onset of monsoon every year.
- Tidal bulge results in high wave energy and action accelerates the process of erosion along the coast.
- Impact of severe tropical cyclone eg. Cyclone Aila in May 2009.
- Climate change induced local sea level rise.
- Submergence and increased wave attack due to storm surges.
- Erosion of marginal embankment along the reclaimed area.
- Degradation of mangrove forest species taking place along the coast accelerating the process of coastal erosion.
- Human activities along the on-shore and off-shore section of the coast.

Plate 1. Coastal Erosion in Sagar Island- a: Incoming of high energy waves; b: Breached embankment near Boatkhali; c: Destruction of a school building due to coastal erosion; d: Degradation of mangroves and other vegetation.

5.2. Change in the Configuration of Sagar Island

With the help of Google Earth, five images of Sagar Island for the years 1984, 1990, 2000, 2010 and 2016 have been analysed for depicting the change in the configuration of the island. It is observed that the size of the island increases in 2016. In 2000, a small part of a broken island is attached to the north-eastern part of the Sagar Island. It is found that in 2016 the area under mangrove also increases in the south-eastern part of the island which is now under the threat of further degradation. Due to the breaching of the embankment, the problem of coastal erosion is increasing in the southern part of the island [17]. The northern peak of the island is now under the influence of accretion and naturally growing mangroves. It indicates that both the processes of erosion and accretion are working together around Sagar Island.

Fig.2. Change in the Configuration of Sagar Island

5.3. Spatio -Temporal Change of Sagar Island

Sagar Island is the western most part of the Ganges-Brahmaputra Delta. It is composed of

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 07 Issue 08
August 2020

riverine and tidal action. It is the largest island in the Sundarbans deltaic complex [25]. The island is severally encountered by a major tidal creek. Primarily the island is built by silt and clay [15]. It can more easily be eroded by waves, tides and cyclonic activities [15]. It is evident from our observation that the total area of the Sagar Island in 1980 was 208.690 sq.km. Since then, the accretional activity started in the region resulting in the increase of the land area. In 1990, the amount further increases to 248.020 sq.km. Severe cyclonic storms and sea level rise were responsible for the erosional activity in the region. In 2000, the land area decreases to 242.784 sq.km. With the impact of accretional processes in the region the total land area increases to 247.248 sq.km. in 2010. The embankment had been constructed to save the land encroachment by the sea. But due to the weakness of the embankment creating material, the embankment has been incapable of facing the encroaching sea waves. Severe erosional activity along the coast of Sagar Island is responsible for the change in the area to 236.497 sq.km. in 2017.

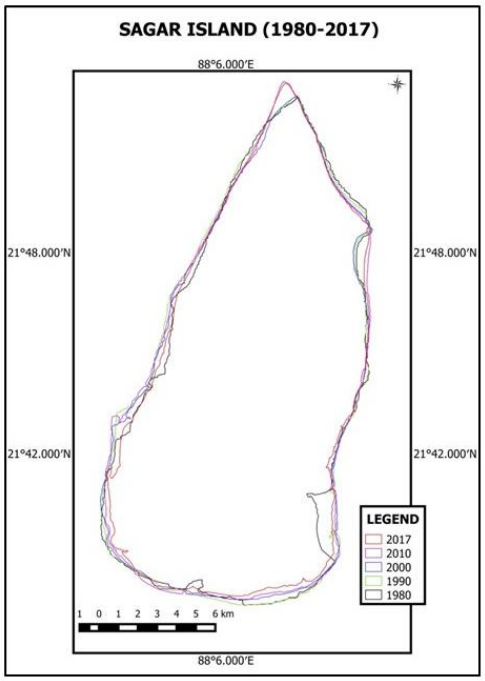


Fig.3. Spatio -Temporal Change of Sagar Island

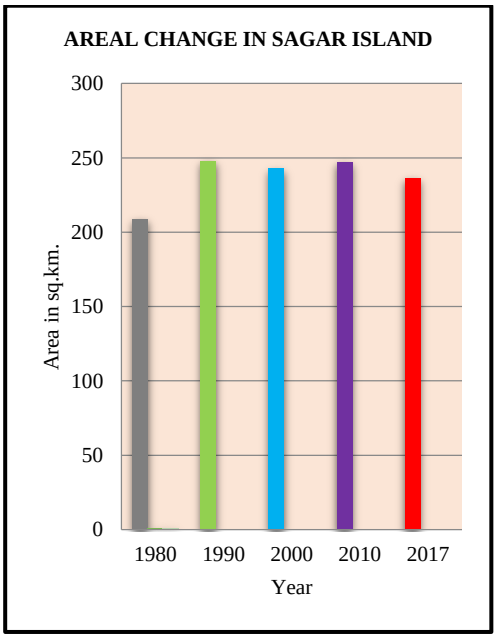


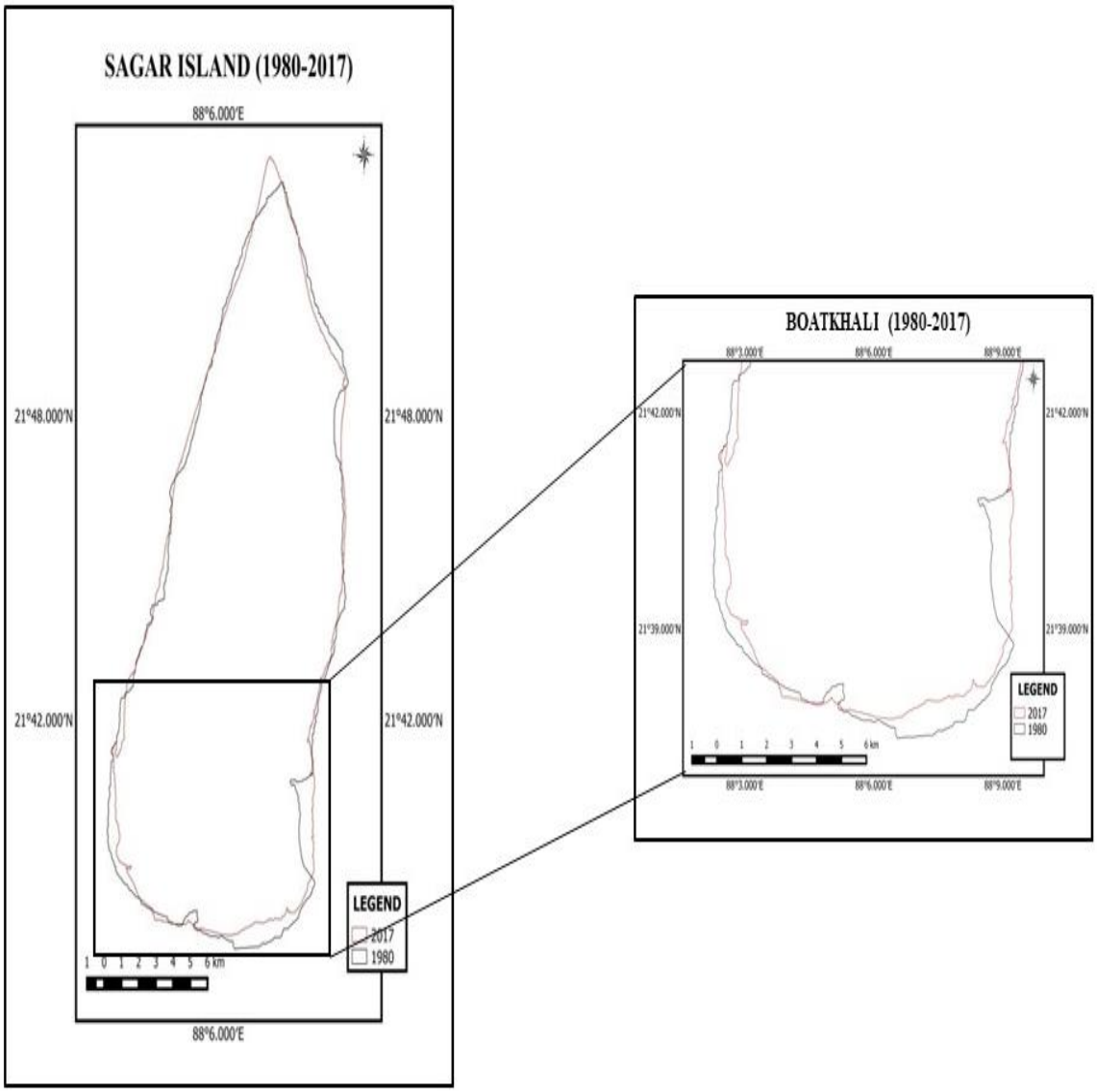
Fig.4. Areal Change in Sagar Island (1980-2017)

5.4. Shoreline Changes in Sagar Island (1980-2017)

The Sagar Island in the Sundarbans delta is composed of mainly silt and clayey sediments. The island has been under the impact of severe coastal erosion. The sea-facing southern part of the island mainly comes under the impact of the high energy waves during the monsoon period when destructive wave climate [26], increased occurrence of tropical cyclone [27] and raised sea levels [28] are mainly the causes of erosion along the coastline. For assessing the shoreline change in Sagar Island and its south-eastern part i.e., the Boatkhali region, the satellite images of 1980 and 2017 have been taken. It can be observed from the map of Sagar Island that in the south-southeast, north-northeast and southwest section, the land is under the influence of erosion. On the other hand, in the north, northeast, west and southeast section of the island, the land is getting deposition. In the case of the Boatkhali region it is found that in the south-southeast and southwest section, the land is under the influence of erosion. On the other hand, in the south-southwest and southeast sections of the region, the land is getting deposition.

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 07 Issue 08
August 2020

Fig.5. Shoreline Change i



n Sagar Island (1980-2017)

5.5. Areal Change in Sagar Island (Erosion-Accretion)

Coastal shorelines are subjected to frequent changes due to coastal processes [29], which are controlled by wave characteristics and the resultant nearshore circulation [30], sediment characteristics, beach form etc. Coasts subjected to accretion are considered less vulnerable areas as they result in the addition of land areas [14]. On the other hand, coasts subjected to erosion are considered to be more vulnerable due to the resultant loss of property and natural habitats [14]. For analysing the areal change in Sagar Island, we have taken the satellite images of 1980 and 2017. It is found that due to the breaching of the embankment, the problem of coastal erosion is increasing in the southern part of the island. The northern peak of the island is now under the influence of accretion and naturally growing mangroves. It can be observed from the chart that the total amount of eroded land is 10.78 sq.km. whereas the total amount of deposited land is 8.16 sq.km. It indicates that both the processes of erosion and accretion are working together around Sagar Island.

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 07 Issue 08
August 2020

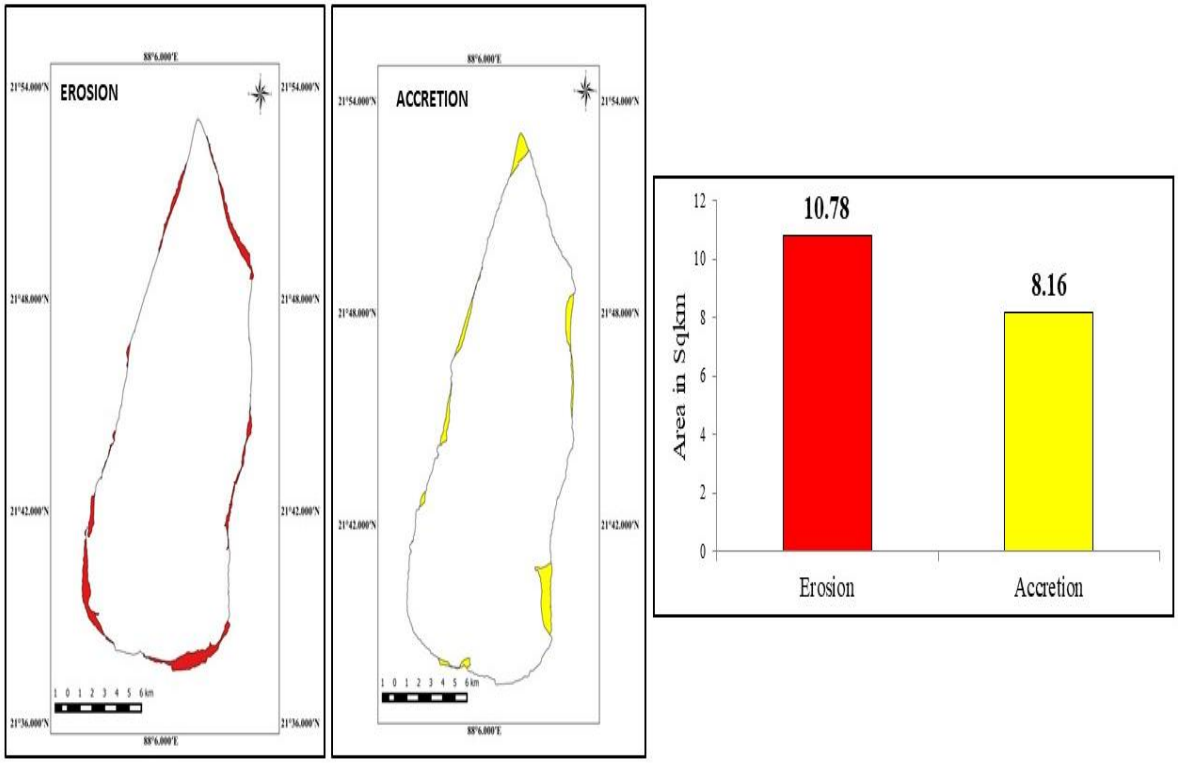


Fig.6. Areal Change in Sagar Island (Erosion-Accretion)

5.6. Landscape Change in Boatkhali (2006-2015)

For analysing the change in the landscape over the years around the Boatkhali region in the south-eastern part of Sagar Island we have taken Google Earth images for the following years- 2006, 2009, 2010, 2013, 2014 and 2015. From the first three images of 2006, 2009 and 2010, it can be observed that most of the land is agricultural area. But with time the breaching of the embankment near the coast results in saltwater intrusion in the Boatkhali region. The previously fertile lands were converted into fishing grounds for the establishment of aquaculture farms. From the next three images of 2013, 2014 and 2015 it can be observed that most of the area is now dedicated to aquaculture farms. Due to the nearness of the farms with high tide line the salinity ranges are high in these areas. The number of settlements has also increased with time. The vegetation land is also found increased over the years.

Fig.7. Landscape Change in Boatkhali region (2006 to 2010)

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 07 Issue 08
August 2020

Fig.8. Landscape Change in Boatkhali region (2013 to 2015)

From the images, it is indicated that over the years the coastline has been shifted inland. The coast comes under the zone of diurnal tidal cycle. The impact of both high tide and low tide results in the mixing of freshwater with the saline water of the sea. During the highest high tide, the saline water reaches the inland resulting saltwater intrusion in the village. Due to high evaporation rate the rate of salt concentration on the surface increases. The salinity is high mainly in the areas near to the high tide line. Away from the coast, the salinity range becomes low. In further inland, in the agricultural lands, the salinity is found to be minimum.

5.7. Problem of Saltwater Intrusion

Saltwater Intrusion [19] is a process by which saltwater infiltrates into a coastal aquifer [31] leading to the contamination of fresh groundwater. In Sagar Island, the problem of coastal erosion is increasing day by day. As the island has been built by silt and clayey sediments, the action of waves, tides and currents have approached the coast and erode the coast more vigorously. With increasing coastal erosion in the southern part of the island, the problem of saltwater intrusion increases further inland. In south-eastern part of Sagar Island, this problem is increasing to a great extent in the village of Boatkhali. The littoral tracts are affected by salt accumulation for their nature of relief i.e., coastal lowlands with a dense network of tidal channels. Salt encrustation is also seen over the coastal low land soil which is frequently affected by the inundation produced by tidal waves during cyclones. A higher evaporation rate in the region may bring up salts from the lower horizons if the moisture regime is connected with the groundwater. Groundwater lies very close to the surface and fluctuations also occur. The saltwater intrudes into the fertile land rendering the agricultural land into degraded fields, the higher salt concentration into the ground resulting in increased salinity in drinking water.

Measuring Soil Salinity: For measuring soil salinity we have taken ten soil samples from different areas of the Boatkhali region of the south-eastern part of the Sagar Island based on the characteristics of the land and distance from the high tide line. Soil samples have been tested using a Salinity Meter. The Electrical Conductivity (EC) of each sample has been calculated.

Table 2: Details of Sample Points and Salinity Values

Sample ID	Latitude	Longitude	Description	Landward Distance from HTL(m)	Salinity (dS/m)
1	21°38'08.08"N	88°07'23.46"E	Behind the Breached Embankment	18.15	10.9
2	21°38'06.74"N	88°07'41.70"E	Fishing Ground	38.15	38.4
3	21°38'06.57"N	88°07'41.55"E	Fishing Ground	32.61	27.0
4	21°38'08.04"N	88°07'46.63"E	Agricultural Field	57.56	25.2
5	21°38'12.96"N	88°07'50.86E	Degraded Paddy Field	189.88	5.04
6	21°38'09.59"N	88°07'32.53"E	Aquaculture Farm	85.46	23.5
7	21°38'12.99"N	88°07'30.94"E	Fishing Ground	167.04	21.0
8	21°38'30.98"N	88°07'24.25"E	Paddy Field	658.89	12.3
9	21°38'30.90"N	88°07'22.33"E	Paddy Field	645.29	6.6
10	21°30'11.67"N	88°07'23.04"E	Fresh Paddy Field	54.49	11.6

Source: Field Survey, 2017

As per the soil salinity classes given by FAO, it is found that paddy fields which are mostly affected by soil salinity fall under the range of 4-8 dS/m of moderately saline soil

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 07 Issue 08
August 2020

class. It is observed that behind the breached embankment the soil salinity value is 10.9 dS/m which indicates a high salinity range. It is the point nearest to the highest high tide line. Due to severe coastal erosion, the saltwater percolates through the ground into the freshwater coastal aquifers raising the levels of soil salinity. Paddy fields near the high tide line are also having high salinity values. The fishing grounds used for aquaculture farming are severely affected by the impact of saltwater intrusion. The highest salinity value is found in the fishing ground in the south-southeast part i.e., 38.4 dS/m. Paddy fields have been degraded in many places due to high saltwater concentration and now converted into fishing grounds.

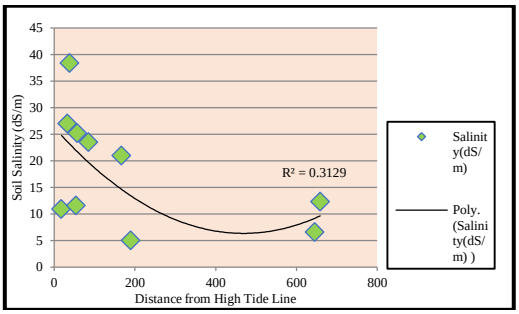


Fig.9. Relationship between Soil Salinity and High Tide Line

Application of manure on these fields to revive to its original state is being difficult than to use the ground for fishing as fish species are more tolerant of salt affected water than plant species. The fish species which are tolerant of these soils are mostly used in these aquaculture farms.

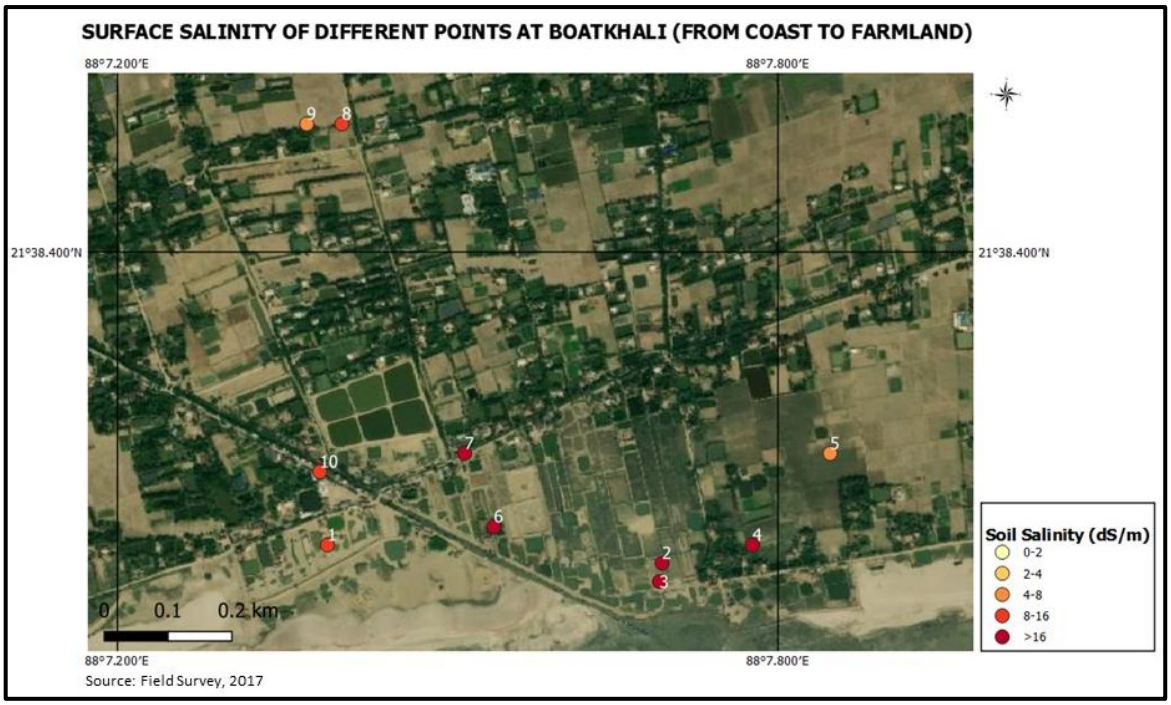


Fig.10. Surface Salinity Map of Boatkhali (From Coast to Farmland)

Soil Salinity Class	Conductivity of the Saturation Extract (dS/m)
Non saline	0-2
Slightly saline	2-4
Moderately	4-8
Strongly saline	8-16
Very strongly saline	>16

Source: Kopikova and Skulkin, 1990 (FAO) [32]

5.8. Landuse and Landcover Change in Boatkhali (1980-2017)

The coastal area of Sagar Island is affected by the activities of both waves and tides. Changes in landuse and landcover occurred from time to time. Landuse and Landcover maps have been prepared for the Boatkhali region for 1980 and 2017 using the supervised image classification technique. It is observed from the map that in 1980 most of the area is agricultural land. Rice is the major crop of the region covering most of the croplands. In the

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 07 Issue 08
August 2020

south-western coast, small patches of mangrove forests are found along with the extreme south-east section. Very few areas are covered with fishing grounds. Mudflats are found in the south-western part of the region. The number of settlements with orchards is found to be very dispersed in nature. The sand concentration along the southern section of the coast is also not so high.

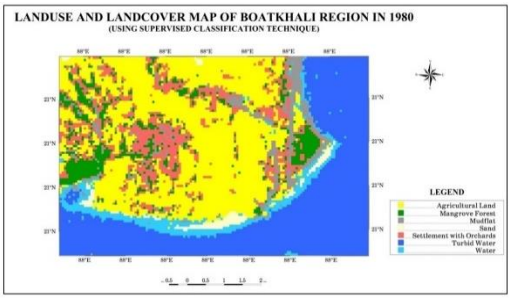


Fig.11. Landuse and Landcover Map of Boatkhali (1980)

In 2017 it is found that the amount of agricultural land is in a decreasing trend. With the growing problem of saltwater intrusion due to severe coastal erosion, most of the fertile lands have been converted into aquaculture farms. The profitability of the income is more in fishing than the cultivation in salt-affected lands. The dominant mangrove species of the region are avicennia marina and casuarinas. The mangrove forest is now found only in the south-eastern part of the region with a very small patch around the south-southwest section. Sand concentration is high along the southern section of the region. Mudflats are found in the southern part. The area under mudflats is in decreasing trend. Sand concentration decreased in 2017. The numbers of settlements have increased over the years along with orchards. Settlements are in the form of small kuccha houses located mainly near the agricultural field.

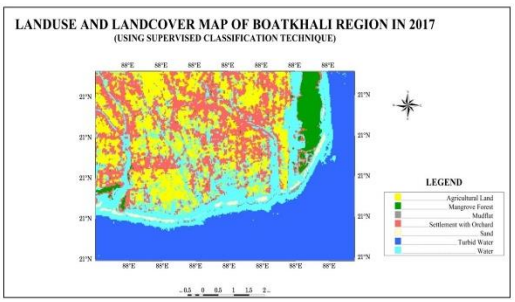


Fig.12. Landuse and Landcover Map of Boatkhali (2017)

Table 3: Change in Landuse and Landcover Features in Boatkhali (1980-2017)

Landuse/Landcover Features	Area in %		Rate of Change (%)	Change
	1980	2017		
Mangrove Forest	7.74	3.73	51.81	↓
Sand	1.80	1.05	41.67	↓
Water	5.40	21.86	304.81	↑
Mudflat	5.28	0.26	96.54	↓
Turbid water	31.52	32.92	4.44	↑
Agricultural Land	36.13	19.57	45.83	↓
Settlement with Orchards	12.14	20.62	69.85	↑

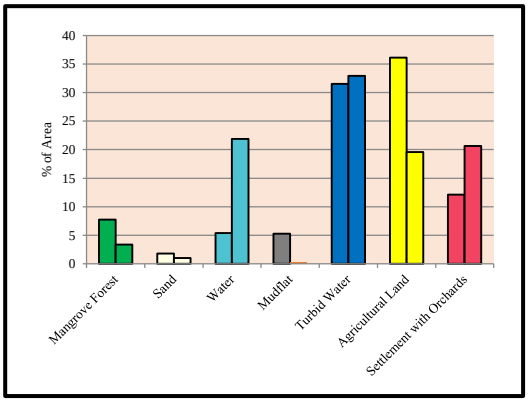


Fig.13. Change in Landuse and Landcover in Boatkhali (1980-2017)

5.9. Perception of the People

5.9.1. Severity Level of Coastal Erosion: Sagar Island is very much vulnerable to the incidence of coastal erosion. The area is affected by the activities of both waves and tides. 84 % of the respondents said that the area is severely affected. The other 16 % of them categorize the area as having moderately affected.

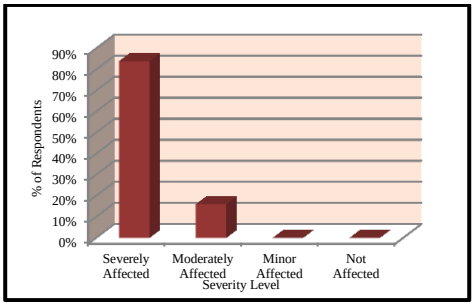


Fig.14. Severity Level of Coastal Erosion

5.9.2. Intensity of Hazards: The intensity of different kinds of hazards are categorised into three

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 07 Issue 08
August 2020

levels of severity. It is found that coastal erosion is the most threatening hazard of the region followed by saltwater intrusion. Flood is the moderately threatening hazard in the region followed by tropical cyclones. Storm surge is the least threatening natural hazard.

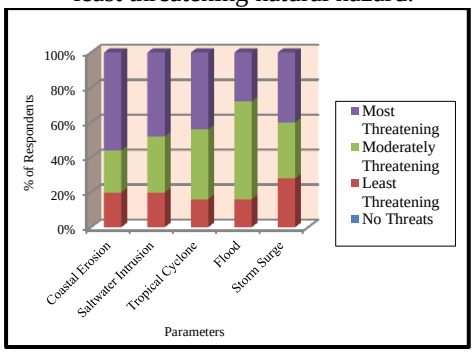


Fig.15. Intensity of Hazards

5.9.3. Frequency of Hazards: The area is having the ground for the occurrences of severe tropical cyclones, devastating floods during the monsoon period and also storm surges mainly in the months of June to September. Highest south and south-westerly wind velocities are 27-30 kmh -1 in the months of April and May. Storm surge is the most frequent hazard of the region followed by flood and then tropical cyclone.

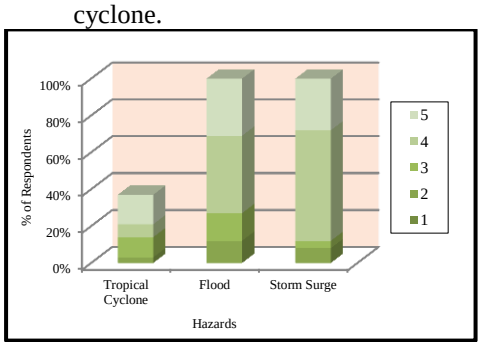


Fig.16. Frequency of Hazards

5.9.4. Level of Satisfaction towards Management: In the concerned region there is the presence of a flood shelter where people approach in case of exposure to the occurrence of any disaster. It is the most satisfying place for them in times of danger. The embankment is created in the region to protect the coastline from further inundation but the failure of the embankment to withstand the impact of high energy waves created grievances among the inhabitants. They are least to moderately satisfied with the management of coastal earthen coastal brick-paved embankment. They are mostly unsatisfied with the Afforestation measures and least satisfied with the relocation policy of the government authority.

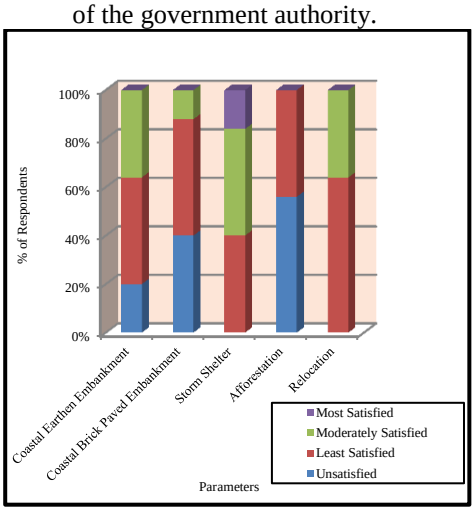


Fig.17. Level of Satisfaction towards Management

5.10. Management of Coastal Defence System

Defending the coastal communities from the clutches of severe coastal erosion is the main aspect of a management plan. The management system includes the protection of people in low land areas from the impacts of flood events and tidal waves. The reclamation of Sagar Island from the forest was started in the early 19th century. After 1917 embankment was repaired to protect the land (Census of India, 1951). The structural design of the embankment, height and materials involved in the construction of embankments are not able to protect the low lands at present. For minimizing the losses incurred by coastal erosion some mitigation measures have been suggested:

- Nature should be given priority as it has the best healing power of regenerating land by natural processes.
- Information dissemination on extreme weather events like storm surges or severe cyclones.

e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 07 Issue 08
August 2020

- Coastal buffers i.e. mangroves area should be strictly protected from the intervention of people.
- Defense of the coastal land should be encouraged by providing beach nourishment.
- Awareness among the people of the affected areas about the protective and ecosystem function of the mangroves.
- Repairing of the brick-paved embankment along with the revetment. Post-monsoon is the best time for building the breached embankment.

Plate 2. Some suggested measures- a: Net Fencing; b: Revetment; c: Afforestation; d: Sea Wall

6. Conclusion

Once the Sagar Island was covered with dense forest. With due time, the area after reclamation from forest converted as land for human settlement. The northern and south-eastern part of Sagar Island shows the signs of accretion after 1980. On the other hand, the southern coast of the region came under the impact of severe erosion. It has been found that from 1980 to 2017, 10.78 sq.km. of the island has been eroded. On the other hand, deposition or accretion has taken place on 8.16 sq.km. of land. Due to the inherent quality of land and breaching of the embankment, the problem of coastal erosion became acute. The problem of saltwater intrusion is increasing with coastal erosion. It leads to further degeneration of the land causing intrusion of saltwater in the southeast part of the Sagar Island. In the village of Boatkhali, due to the problem of saltwater intrusion into the agricultural fields, people were forced to change their occupation from agriculture to fishing. Agricultural fields have been degraded due to saltwater intrusion resulting in decreasing crop yield. These lands are now used for aquaculture farming due to high salt concentration in the soil. Higher salinity is found along the areas near the high tide line. Fishing grounds have high saltwater concentration. The number of aquaculture farms shows an increasing trend. Most of the inhabitants of the region are living with a low standard of living and are unsatisfied with the government measures of protecting land from the impact of high energy waves. The failure of the embankment creates grievances among the villagers. For the prevention of coastal erosion and the problem of saltwater intrusion, not only the government agencies but also the local communities should be incorporated in the management plan.

7. References

[1] Sanderson, P. G., Eliot, I., Hegge, B., & Maxwell, S. (2000). Regional variation of coastal morphology in southwestern Australia: a synthesis. *Geomorphology*, *34*(1-2), 73-88.

[2] Zhao-sen, L. U. O. (2004). Sediment transport under the coexisting action of waves and currents and the prediction of sudden sedimentation in navigation channel [J]. *Journal of Sediment Research*, *6*, 1-9.

[3] Walters, R. A., Gillibrand, P. A., Bell, R. G., & Lane, E. M. (2010). A study of tides and currents in Cook Strait, New Zealand. *Ocean dynamics*, *60*(6), 1559-1580.

[4] Tubman, M. W., & Suhayda, J. N. (1977). Wave action and bottom movements in fine sediments. In *Coastal Engineering 1976* (pp. 1168-1183).

[5] Sachs, J. D., & Warner, A. M. (2001). The curse of natural resources. *European economic review*, *45*(4-6), 827-838.

[6] Arkema, K. K., Guannel, G., Verutes, G., Wood, S. A., Guerry, A., Ruckelshaus, M., ... & Silver, J. M. (2013). Coastal habitats shield people and property from sea-level rise and storms. *Nature climate change*, *3*(10), 913-918.

[7] Sweet, W. V., & Park, J. (2014). From the extreme to the mean: Acceleration and tipping points of coastal inundation from sea level rise. *Earth's Future*, *2*(12), 579-600.

[8] Bagdanavičiūtė, I., Kelpšaitė, L., & Soomere, T. (2015). Multi-criteria evaluation approach to coastal vulnerability index development in micro-tidal low-lying areas. *Ocean & Coastal Management*, *104*, 124-135.

[9] Shepardson, D. P., Niyogi, D., Choi, S., & Charusombat, U. (2011). Students' conceptions about the greenhouse effect,

global warming, and climate change. *Climatic Change*, *104*(3-4), 481-507.

[10] Hanson, H., & Lindh, G. (1993). Coastal erosion: an escalating environmental threat. *Ambio*, 188-195.

[11] Nandy, S., & Bandyopadhyay, S. (2011). Trend of sea level change in the Hugli estuary, India.

[12] Hazra, S., Ghosh, T., DasGupta, R., & Sen, G. (2002). Sea level and associated changes in the Sundarbans. *Science and Culture*, *68*(9/12), 309-321.

[13] Purkait, B. (2009). Coastal erosion in response to wave dynamics operative in Sagar Island, Sundarban delta, India. *Frontiers of Earth Science in China*, *3*(1), 21.

[14] Thomas, J. V., Arunachalam, A., Jaiswal, R. K., Diwakar, P. G., & Kiran, B. (2014). Dynamic land use and coastline changes in active estuarine regions-a study of sundarban delta. *The International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences*, *40*(8), 133.

[15] Gopinath, G., & Seralathan, P. (2005). Rapid erosion of the coast of Sagar island, West Bengal-India. *Environmental Geology*, *48*(8), 1058-1067.

[16] Kumar, P. D., Gopinath, G., Laluraj, C. M., Seralathan, P., & Mitra, D. (2007). Change detection studies of Sagar Island, India, using Indian remote sensing satellite 1C linear imaging self-scan sensor III data. *Journal of Coastal Research*, *2007*(236), 1498-1502.

[17] Banerji, R., Guha, I., Roy, C., Roy, J., & Bhattacharya, S. (2012). Adaptation in case of inundation of islands: an exploratory study from Indian Sundarbans, a world heritage site. In *ISEE 2012 Conference–Ecological Economics and Rio* (Vol. 20).

[18] Roy Chowdhury, B., & Sen, T. (2013). Coastal Erosion and Its Impact on Sagar Island,(S) 24 Parganas, WB.

[19] Chang, S. W., Clement, T. P., Simpson, M. J., & Lee, K. K. (2011). Does sea-level rise have an impact on saltwater intrusion?. *Advances in water resources*, *34*(10), 1283-1291.

[20] Temmerman, S., & Kirwan, M. L. (2015). Building land with a rising sea. *Science*, *349*(6248), 588-589.

[21] Rudra, K. (2014). Changing river courses in the western part of the Ganga–Brahmaputra delta. *Geomorphology*, *227*, 87-100.

[22] Mukherjee, K. N. (1983). History of settlement in the Sundarbans. *Indian Journal of Landscape Systems and Ecological Studies*, *6*, 1-19.

[23] Chakraborty, S. (2013). Delineation of morpho-structural changes of some selected islands in the Ganga delta region, West Bengal, India–a spatio-temporal change detection analysis using GIS and remote sensing. *Int J Sci Nat*, *4*(3), 499-507.

[24] Chandramouli, C., & General, R. (2011). Census of India 2011. *Provisional Population Totals. New Delhi: Government of India*, 409-413.

[25] Subhasish Das et.al (2013): "Sediment Transport and Island Change Detection: a case study from Sagar Island, West Bengal; Int. J. Geo Sci. & Tech.; ISSN- 2321-2144; Vol. 1 (1) ;pp. 41-62

[26] Hallermeier, R. J. (1980). A profile zonation for seasonal sand beaches from wave climate. *Coastal engineering*, *4*, 253-277.

[27] Woodruff, J. D., Irish, J. L., & Camargo, S. J. (2013). Coastal flooding by tropical cyclones and sea-level rise. *Nature*, *504*(7478), 44-52.

[28] Roberts, D. L., Karkanas, P., Jacobs, Z., Marean, C. W., & Roberts, R. G. (2012). Melting ice sheets 400,000 yr ago raised sea level by 13 m: Past analogue for future trends. *Earth and Planetary Science Letters*, *357*, 226-237.

[29] Kumar, V. S., Pathak, K. C., Pednekar, P., Raju, N. S. N., & Gowthaman, R. (2006). Coastal processes along the Indian coastline. *Current science*, 530-536.

[30] Sonu, C. J. (1972). Field observation of nearshore circulation and meandering currents. *Journal of Geophysical Research*, *77*(18), 3232-3247.

[31] Chang, S. W., Clement, T. P., Simpson, M. J., & Lee, K. K. (2011). Does sea-level rise have an impact on saltwater intrusion?. *Advances in water resources*, *34*(10), 1283-1291.

[32] Antonellini, M., Mollema, P., Giambastiani, B., Bishop, K., Caruso, L., Minchio, A., ... & Gabbianelli, G. (2008). Salt water intrusion in the coastal aquifer of the southern Po Plain, Italy. *Hydrogeology journal*, *16*(8), 1541.

[33] Kopikova, L.P. & Skulkin, V.S. (1990). The assessment of soil salinity on the basis of combined data on water extracts and saturated soil-paste extracts. The development and properties of poor steppe soils within the Jizzakh Region (Uzbekistan). Moscow, Dokuchaev Soil Science Institute, pp. 74-81.