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Research article

Coastline change and coastal islands development in the Feni estuary of Bangladesh through RS and GIS

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Abstract: In coastal areas, to take any development plan, it is important to determine the stability of the coast and coastal islands. Therefore, the present research took an initiative to illustrate the development of coastal islands in the Feni estuary of Bangladesh through Remote Sensing (RS) and Geographic Information System (GIS) techniques. Multi-dated Landsat images of 1978, 1989, 2014 and 2020 were used in the study. The research reveals that in 1978, 1989, 2014 and 2020, the total area of various islands in the estuary was 377, 650, 894 and 1063 km^2, respectively. The islands show cyclical growth and erosion, but their main components have existed for decades. During the period from 1978 to 1989, 1989 to 2014 and 2014 to 2020 about 330, 386 and 379 km^2 of new land added to the existing land mass and about 57, 142 and 210 km^2 of existing land eroded, respectively. Finally, from 1978 to 2020, the size of the islands increased by about 14.64 km^2 yr^{-1}. During the same period about 110 and 40 km^2 lands along the coastline were eroded and accreted, in the north-western and eastern parts of the estuary, respectively. The study further reveals that the islands of the estuary have developed over the past few decades, except Sandwip. Finally, the outputs of this study will be helpful for policy makers and planners for sustainable estuary management.

Keywords: bhasan char; erosion-accretion; estuary management; Bengal delta

1. Introduction

The coast and its islands face different natural and anthropogenic processes like see level rise, erosion-accretion, storm surges, coastal inundation, channel migration along with human-induced environmental impacts, etc [1–6]. In Bangladesh, they also face these challenges, and as a result, change of coastlines, islands morphology, positions and areas [7–12]. Hence, sustainable management of coast and coastal islands has emerged as a matter of concern. Feni Estuary (Figure 1) in Bangladesh is very dynamic and distinctive in character due to its geographical location and hydro-geomorphic settings. Many offshore islands are present in this estuary. These islands experienced significant morphological changes over time. The Bangladesh government took many initiatives to develop the coastal areas of the country in connection with different coastal islands. To take any development plan, it is essential to define the coastline and coastal islands consistency of the area. Several researches conducted on coastline change, erosion-accretion of the coast, and morphological change of different coastal islands in the country [13–18]. Till now there is no systematic research conducted about coastline change and coastal islands development in the Feni Estuary, Bangladesh. This research gap inspired the authors to carry out the present work to accomplish the space. The output of the research will be helpful for the Government of Bangladesh and different agencies to adopt the necessary management plan for sustainable management of the area.

The Remote Sensing (RS) and Geographic Information System (GIS) have proved powerful tools in various geomorphological studies [19–25]. Keeping in view its distinct advantages over conventional methods in landform evolution, the present study used these techniques to delineate the coastline and coastal islands development in this estuary. Many studies also used these techniques to delineate coastal dynamic, coastline change, estimation of erosion and deposition along Bangladesh coast and abroad [2,26–30]. The main objectives of the research were: a) delineate erosion and accretion of different islands and coastline, and b) understand the process of evolution of different islands. Therefore, the findings of this research will be helpful to understand the coastline change and coastal islands development of this estuary, and accordingly it will be supportive for future development plans and sustainable management of the estuary.

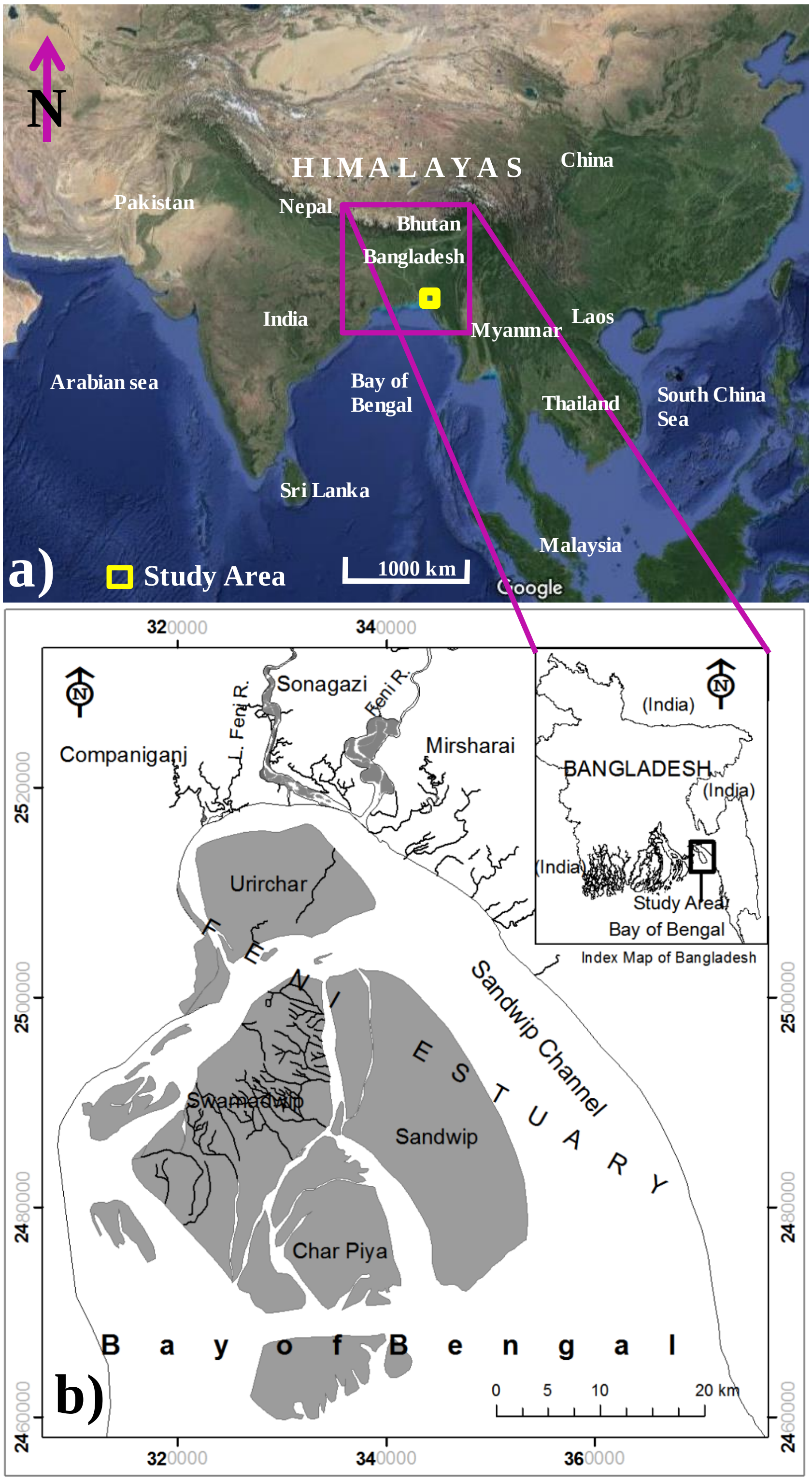


Figure 1. a) Regional map showing Bangladesh, Himalayas, Bay of Bengal and surroundings with location of study area; b) representing the study area.

2. Materials and methods

2.1. Study area

The Bengal Delta is one of the largest deltas in the world [31,32]. The main progradation of the delta is continuing to the south into the Bay of Bengal. The major sediment sources for the delta are the Ganges, Brahmaputra, and Meghna (GBM) river systems. These river systems are estimated to discharge about 1.8 to 2.5 billion tons of sediments per year [31,33]. The Feni estuary is a part of the delta, and consequently these river systems are the major source of sediment in this estuary to build up different islands [16]. The Feni and Little Feni rivers (Figure 1) also carry around 2 million tons of sediments per year and discharge into this estuary [34]. The coastal islands development of this estuary is directly related to the GBM rivers sediments, and also sediments from the Feni and Little Feni rivers. The area tectonically lies between western limit of the Chittagong Tertiary Folded Belts and the Hatia Trough tectonic element of the Bengal Basin in the west [35]. The average rainfall in this area is ~ 500–4000 mm yr^{-1} and means daily temperature varies about 12.7 °C in the dry season to 32.3 °C earlier to the beginning of monsoon (Bangladesh Meteorological Department). Prevailing winds, from November to February are from north and north-west and sometimes from south, from March to May they are sometimes from south and sometimes from south-east, and from June to October they are mainly from south-west and sometimes from south (Figure S1). Strong winds blow during the summer. The wind speed mostly remains lowest in the winter months of December to February. The monthly wind speed remains approximately 2 to 5 knots throughout the year (Figure S2). Huge freshwater from the upstream, a strong seasonality in weather and flimsy low-lying geomorphic situation of this estuary, make itself susceptible to various natural risks and disasters [9]. During spring and fall transitions, strong depressions lead to tropical storms in the areas [18,36,37], consequently, inundation of the low-lying lands, and therefore loss of lives and properties [38]. In 1970, 1991 and 1997 the Sandwip Island (Figure 1) of this estuary was affected by the overwhelming cyclones with the highest recorded storm surge (height ranging between 0.90 and 13.64 m) [39,40]. The tidal data (Source-Bangladesh Inland Water and Transport Authority (BIWTA)) reveals that the highest high water in the area during the winter season reaches to about 3.3 m and the lowest low water reaches to about 0.50 m from the sea level. On the other hand, in the rainy season the highest high water reaches to about 4.1 m and the lowest low water reaches to about 1.00 m from the sea level.

2.2. Data acquisition and preparation

Multi-dated Landsat images representing 1978, 1989, 2014 and 2020 were collected from the USGS website (http://glovis.usgs.gov), which covers the dry period (winter season/post monsoon) as well as during low tide images, and used for this study (Table 1; Figure 2). As, cloud free images are generally available in the dry period. However, the variation of temporal range amongst the considered periods happened because of unavailability of images during low tides and also cloud free images at regular intervals. Resolutions of images are 60 meter (m), 30 m, 30 m and 30 m, respectively. It is worthy to state that Landsat MSS data from 1978 with a spatial resolution of 60 m was resampled to 30 m using the nearest neighbour technique by Erdas imagine 2010 in order to match the spatial resolution of Landsat TM/ETM+/OLI data of 30 m resolution, and tried to minimize the error range of images, accordingly our earlier research [41,42].

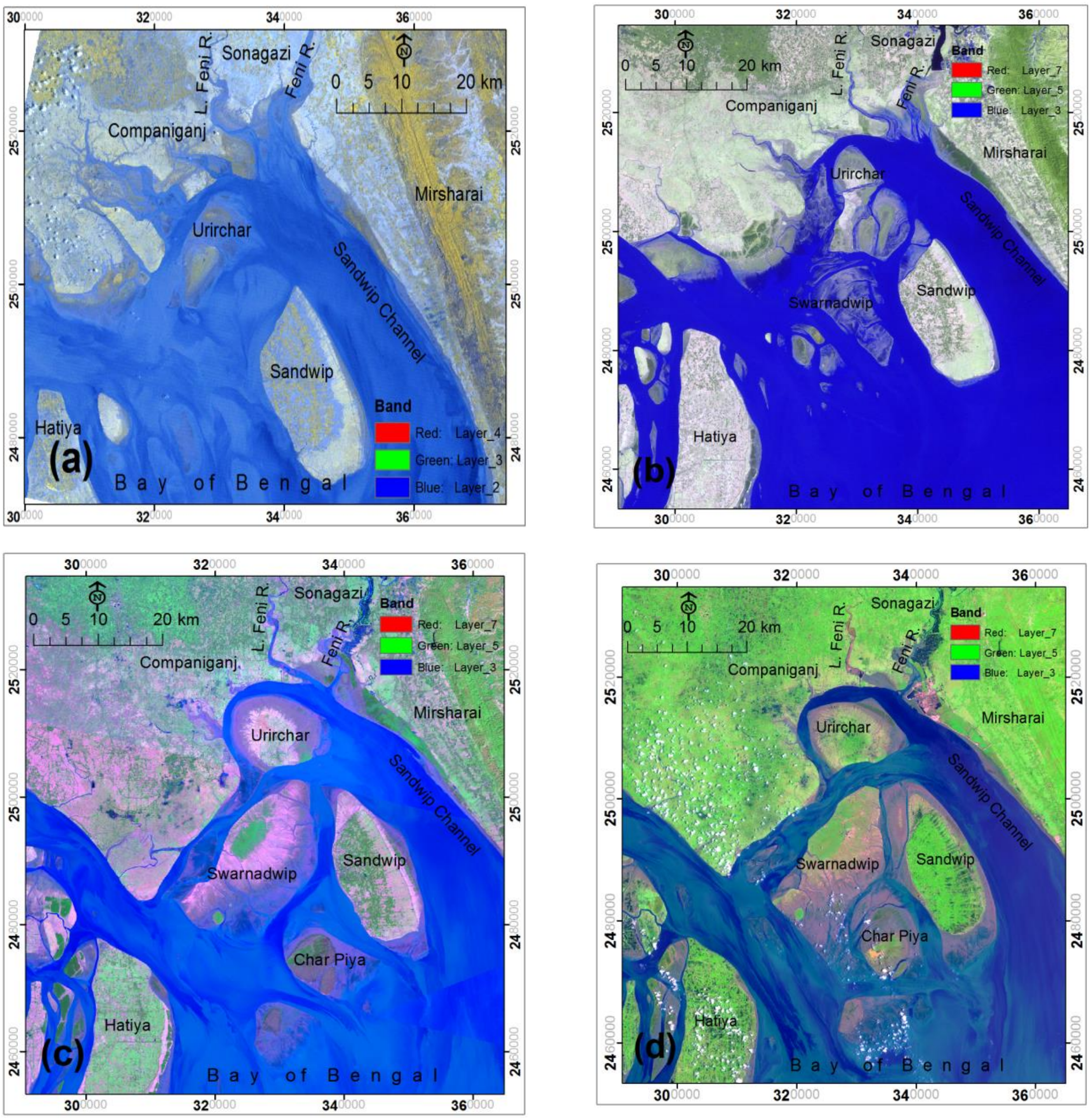


Figure 2. Feni Estuary and islands in Landsat images at different times (a) 1978; (b) 1989; (c) 2014 and (d) 2020.

All the images were georeferenced in WGS 84 UTM Zone 46N projection system. Required processing of images like layer stack, mosaic, image enhancement and geoprocessing was done in Erdas imagine 2010 and Arcmap 10. Besides, the recent satellite images, the historical maps of 1853–1857 [17] and the James Rennell's maps of 1779 [43] were used in this research. The Rennell's maps were planimetrically [44]. Therefore, only approximate georeferencing was carried out. The historical maps of 1853–1857 were mapped on Everest spheroid. Therefore, the coordinates system of the 1853–1857 maps were transformed to the WGS-84 coordinates system by Arcmap 10 to compatible with the Landsat images (WGS 84 projection system), as it is a standard practice [22,23,41].

Table 1. Landsat Imagery used in this work.

Satellite Sensor	Date of Acquisition	Time of Acquisition	Path and row	Spatial Resolution	Tidal condition
MSS	15 April, 1978	03:13:41	146/44	60	Falling
TM	22 February, 1989	03:51:01	136/44	30	Falling
		03:51:03	136/45		
L8 OLI	19 February, 2014	04:19:27	136/44	30	Falling
		04:20:04	136/45		
L8 OLI	10 May, 2020	04:18:18	136/44	30	Falling
		04:18:41	136/45		

2.3. Delineating coastline, islands development, and estimation of erosion and deposition rates of the islands

The coastlines are much more dynamic in nature and changing all the time due to its diurnal tidal effect. Therefore, the precise shoreline delineation is to some extent complex [6,10]. Because, the intertidal areas are inundated during high tide and during low tide it is free from tidal water. However, for shoreline delineation, some researchers considered the high tide period images [9], and therefore the intertidal areas excluded from analysis. But some researchers considered the low tide period images [8]. Some researchers also used mixed time images at a time i.e. both high tide and low tide images [10,15,45]. In the current research, low tide images were used for analysis, and as a result the intertidal areas also added to the findings. The visual image interpretation was carried out using indicative and deductive analysis of various image elements (tone, texture, pattern, shape, size and terrain elements like landform, erosion, deposition and landuse) to delineate the coastline and islands, their erosional and depositional pattern, as it is viewed as a standard practice to delineate coastline and different morphological features in previous works [2,22,41,46,47]. Recently, many researchers used the Digital Shoreline Analysis System (DSAS) to delineate coastal change [30,48]. However, many scholars stated that visual image interpretation and image enhancement techniques are also very useful to monitor the coastline [6,49]. Demarking the land-water boundary using Landsat images is a challenging task. To overcome this situation, a combination of different Landsat bands [22,41,45] and a soil-vegetation limit approach [50] were employed to identify the land-water boundary. Previous studies [41,45,49–51] reveal that these approaches are highly effective. Arcmap 10 was used for digitizing the images. Point mode method was used to digitize. Assessment of erosion and deposition, polygons of two particular years were taken (superimposing) using the union method of Analysis tool.

3. Results

3.1. Coastal Islands development

The study implies that in 1978, 1989, 2014 and 2020 the total area of islands in the Feni Estuary was about 377, 650, 894 and 1063 km^2, respectively. During the period from 1978 to 1989, 1989 to 2014 and 2014 to 2020 about 330, 386 and 379 km^2 new land added to the existing land mass, and about 57, 142 and 210 km^2 existing land eroded, respectively (Table 2; Figures 3 and S3). Finally, from 1978 to 2020 the area of the islands was increased at a rate of about 14.64 km^2 yr^{-1}) (Figure S4).

Sandwip Island is an old island in this estuary [43,52]. The research reveals that in 1978, 1989, 2014 and 2020, the total area of the island was about 261, 262, 250 and 328 km^2, respectively (Table 3; Figure S5). During the period from 1978 to 1989, 1989 to 2014 and 2014 to 2020 about 15, 27 and 85 km^2 new land added to the existing land mass, and about 14, 44 and 7 km^2 of existing land eroded, respectively (Table S1; Figure 5). Therefore, during the periods from 1978 to 1989 and 2014 to 2020, the island was in the gaining phase (Table S2; Figure 6). Although, during the period from 1989 to 2014 the island was losing phage. The study reveals that from 1978 to 1989 and 1989 to 2014, the western and southwestern part of the island were eroded (Figure 3a,b). On the contrary, the northern and esatern parts were prograded. However, during the period from 2014 to 2020, the land was enlarged on all sides (Figure 3c). Though, more land accreted in the northwestern and southwestern parts. The earlier study also reveals that the different parts of this island show cyclic accretion and erosion [7,15,52]. Likewise the erosion-accretion, the water depths surrounding the island also exhibit similar dynamics [15]. Finally, it is significant that the main part of the island still exist after facing the erosion-accretion processes over the longer times.

Urirchar is another island in the estuary. The study implies that in 1978, 1989, 2014 and 2020 the total area of this island was about 74, 160, 155 and 146 km^2, respectively (Table 3; Figure S5). During the periods from 1978 to 1989, 1989 to 2014 and 2014 to 2020 about 101, 81 and 10 km^2 new land added to the existing land mass and about 15, 49 and 19 km^2 existing land eroded, respectively (Table S1; Figure 5). During the period from 1978 to 1989, the island was in the gaining phase (Table S2; Figure 6). However, during the periods from 1989 to 2014 and 2014 to 2020 the island was in a losing phage. The study reveals that from 1978 to 1989 the land accreted in the northern, western and southeastern parts (Figure 3a).

Table 2. Total erosion, accretion, gain/loss of islands (km^2) at different time duration.

Duration	1978 to 1989	1989 to 2014	2014 to 2020
Accretion	330	386	379
Erosion	57	142	210
Gain/Loss	+273	+244	+169
Gain/Loss (yr^{-1})	+24.81	+9.76	+28.16

Note: (+) gain and (-) Loss.

Table 3. Area (km^2) of different islands from 1978 to 2020.

Year	1978	1989	2014	2020
Sandwip	261	262	250	328
Urirchar	74	160	155	146
Swarnadwip	0	109	311	281
Char Piya	0	0	108	101
Other Islands	42	119	70	207

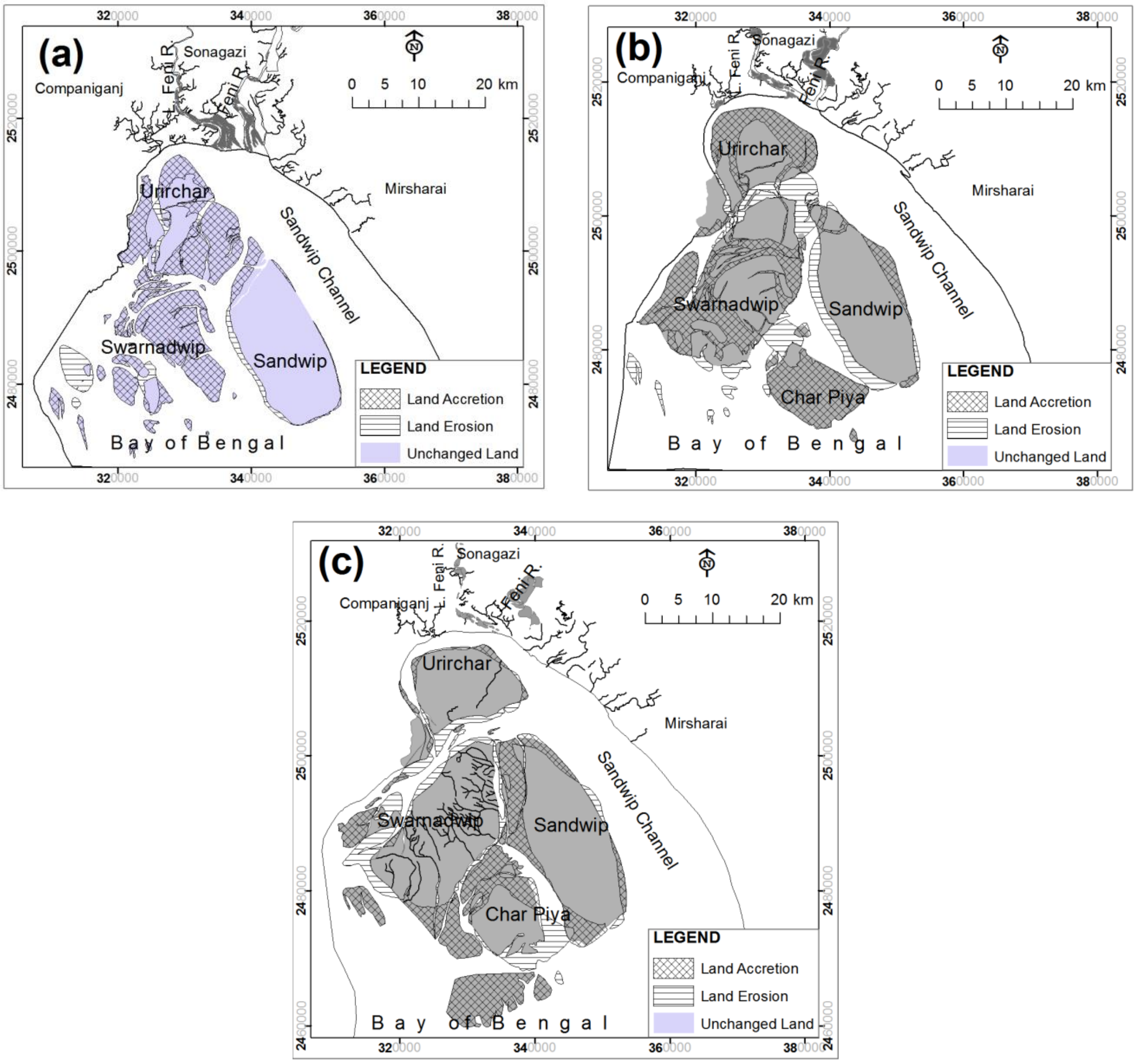


Figure 3. Erosion and accretion of islands from (a) 1978 to 1989; (b) 1989to 2014 and (c) 2014 to 2020.

But during the period from 1989 to 2014, the land accreted in all parts except the southern part. In the southern part, the land was eroded (Figure 3b). Similar trend was observed during the period from 2014 to 2020. Finally, like the Sandwip Island, the main part of this island exists over the past few decades after faced the erosion-accretion processes. Though, this island is not so old like Sandwip Island. Due to the newly formed, there is no settlement there, and the island is only covered by tiny grassland and still under growth. However, in Rennell's maps an island namely Bomiry Land (Figure 4a) was present in the same area. The existence of the island was also found in the Hunters map (Figure 4b). However, later time it was eroded, and then Urirchar again developed in the same area.

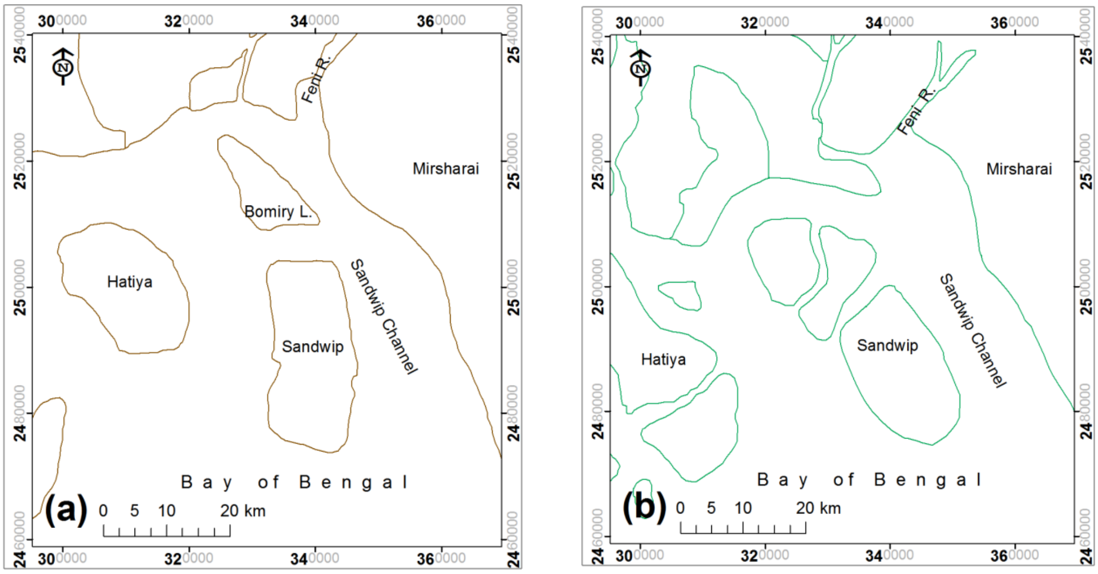


Figure 4. Feni Estuary and islands (a) in Rennell's maps and (b) Hunter maps.

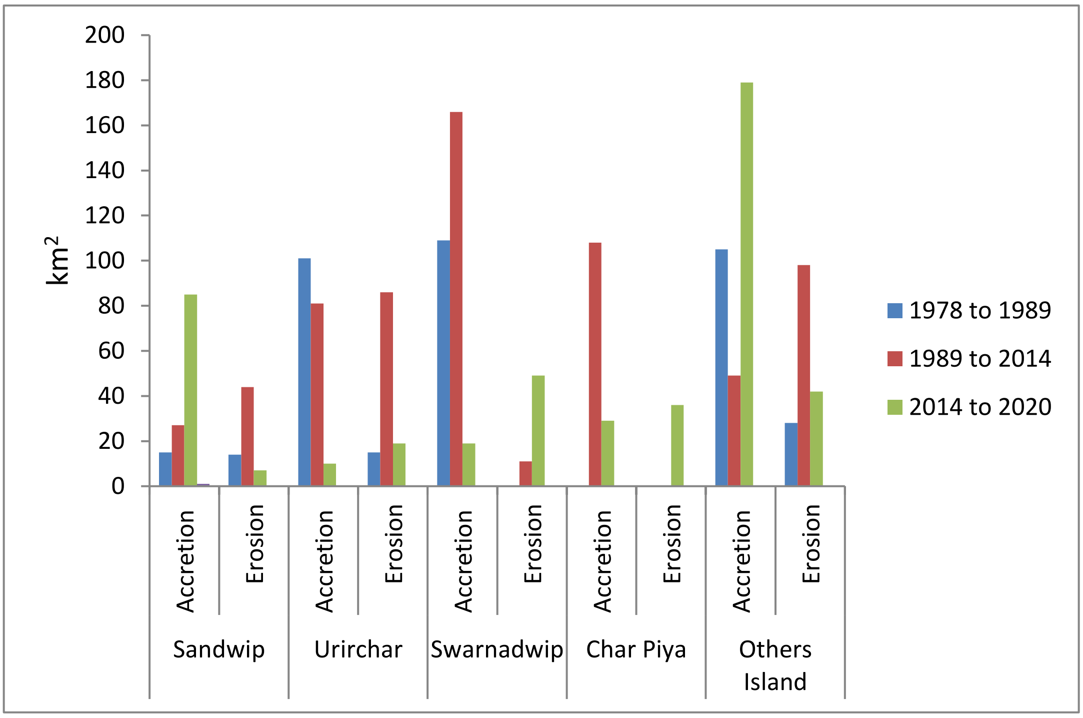


Figure 5. Erosion-accretion (km^2) of different islands at different time duration.

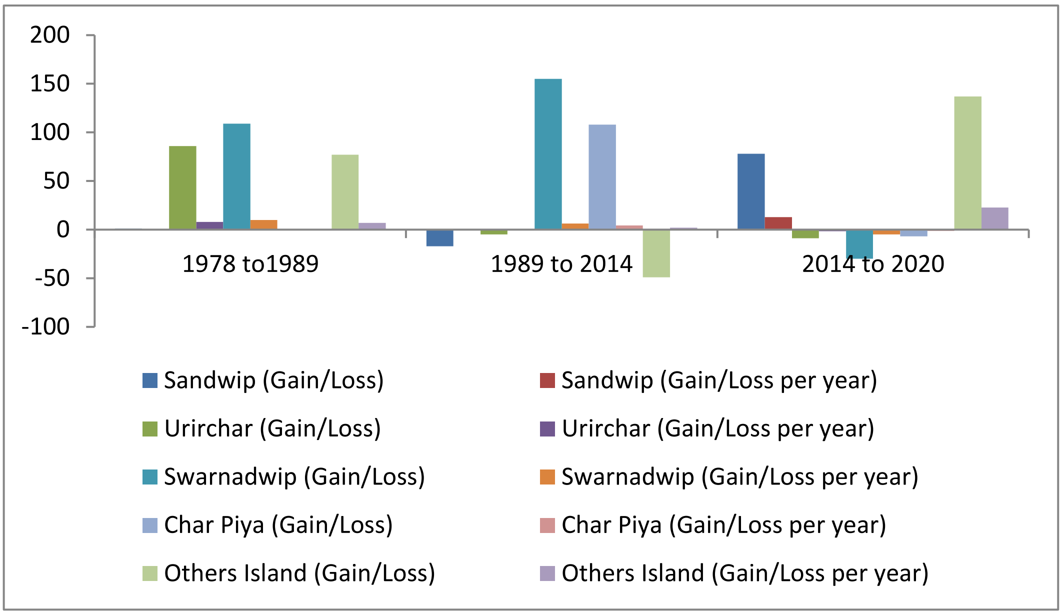


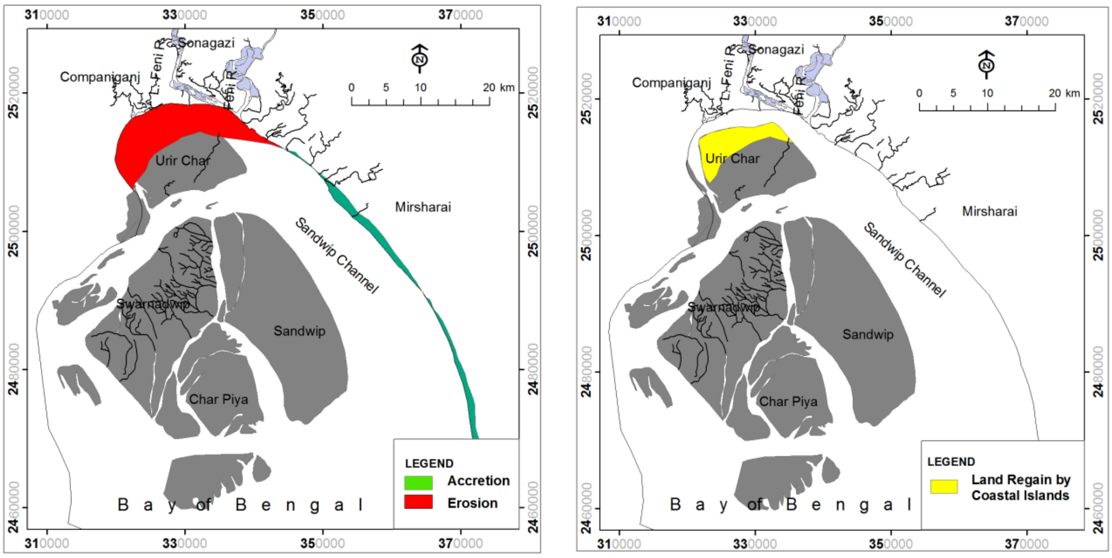
Figure 6. Gain/loss (km^2) and Gain/loss per year of different islands at different time duration.

Swarnadwip is a recently developed island in the estuary. In the 1978 image, the island was absent (Figure 2a). However, in the 1989 image it was observed (Figure 2b). Due to the newly formed, it is only covered by tiny grassland and also there is no settlement. The area of the island in 1989, 2014 and 2020 was about 109, 311 and 281 km^2, respectively (Table 3; Figure S5). During the period from 1989 to 2014 and 2014 to 2020 about 166 and 19 km^2 new land added to the existing land mass and about 11 and 49 km^2 previous land eroded, respectively (Table S1; Figure 5). During the period from 1989 to 2014, it was in the gaining phase (Table S2; Figure 6). However, after that, during the period from 2014 to 2020, it was losing phage. The study reveals that from 1989 to 2014, the land accreted in the southwestern part and eroded in the southeastern part (Figure 3b). But, from 2014 to 2020, the land eroded in the southwestern, western and northwestern parts, respectively and accreted in the southeastern part (Figure 3c). Finally, it is important that like the Sandwip and Urirchar, the main part of this island exists over the past few decades after facing the erosion-accretion processes. Another important thing is that though this island is not so old, but the area of this island is more or less equal to Sandwip island.

The Char Piya (also known as Bhasan Char) is another newly formed island in the estuary. In 1978 and 1989 images the island was absent (Figure 2a,b). But in the 2014 image the island was present (Figure 2c), and the area of the island was 108 km^2 (Table 3; Figure S5). However, in 2020 the area of the island decreased to about 101 km^2 (Table 3). During the period from 2014 to 2020, about 29 km^2 new land added to the existing land mass and 36 km^2 land eroded, respectively (Table 3; Figure 5). During that period, the land eroded in the southeastern part of the island (Figure 3c). However, land accreted in the northern part. But the main part of this island still exists similar to other major islands of the estuary. Due to the newly formed, the island is covered by tiny grassland like Urirchar and Swarnadwip. Recently, the government took initiative to develop different infrastructure of this island, and used it as a settlement and other purposes. Besides the major islands, some other small islands also formed in different times in the estuary (Figure 2). However, these islands were again demolished by coastal erosion. In 1978, 1989 and 2014 the total area of these islands was about 42, 119 and 70 km^2, respectively (Table 3).

3.2. Coastline change

Image analysis shows that during the period from 1978–2020 about 110 km^2 of land eroded from the mainland at a rate of about 2.62 km^2 yr^{-1} and about 40 km^2 of land accreted along coastline at a rate of about 0.95 km^2 yr^{-1} (Figure 7a). However, about 46 km^2 of eroded land was regained by the Urirchar at a rate of about 1.10 km^2 yr^{-1} through offshore island development (Figure 7b). The land eroded mainly in the northwestern part of the estuary i.e. the southern part of Companiganj Upazila. However, land accreted in the eastern part i.e. the western part of Mirsharai (Figure 7a).



(a) (b)

Figure 7. (a) Accretion and Erosion along coastline in the estuary from 1978–2020; (b) a part of the eroded land regain by offshore island development.

4. Discussion

The study revealed that the main islands in the estuary show cyclic growth and erosion phenomena (Figure 3). The size, shape and location of these islands are changing over time. However, major parts of the islands have existed for the past few decades, and the islands have increased in area at a rate of 14.64 km^2 yr^{-1} from 1978–2020. These islands play an important role in estuarine flow and sediment distribution. During the same period about 110 and 40 km^2 lands along the coastline were eroded and accreted, in the northwestern and eastern parts, respectively. Estuaries have long-term effects from both endogenous factors, such as channel mouth flow resulting from delta formation processes, and exogenous factors, such as changes in base level due to climate change [16,32]. Furthermore, the river and the small offshore island are geologically vulnerable due to their remoteness and isolation. Due to high tidal action and high discharge with sediment flux from upstream, the estuary is highly dynamic in character [16,32], and sediment river flow distribution processes change very rapidly. Due to the highly buoyant character (vast freshwater from upstream, a strong seasonality of weather and weak low topographic conditions) and random cyclones in different directions [4,16,53] the islands show cyclic erosion and growth. However, the coastal region of Bangladesh is composed of huge resources. But it is facing various challenges such as sea level rise, storm surge, salt water intrusion, drainage congestion, coastal headland erosion, etc [2–4,54,55]. One of the major erosions is occurring in the estuarine region, where major rivers enter the Bay of Bengal [2]. However, new islands have developed in parts of the estuary [2]. But due to erosion the existing islands are always changing their shape, position and sometimes completely destroyed. Although encroachment is a dominant process, erosion in the country's densely populated tidal flats leaves thousands of people landless and homeless every year [7]. But the country needs more land resources due to its heavy population (total population is about 165 million; density 1100/km^2) demand. So now the country wants land in coastal and offshore areas, and the coastal people have been exploiting the land in various ways. Therefore proper use and management of coastal areas is very important for Bangladesh. The newly developed islands in the Feni estuary are used for settlement and other purposes. It is therefore important to look carefully at the issue as it is located in a dynamic coastal zone and takes necessary measures for sustainable management as well as through proper land use which can conserve a lot of property and resources, can contribute to an overall positive national economy outlook. As a result, it has attracted much attention from researchers, policy makers and planners for the sustainable management of the area. Therefore, the output of the present paper will be helpful for policy makers and planners to adopt future plans for sustainable estuary management.

5. Conclusions

The research revealed that the major islands of the estuary have developed over the past few decades, except Sandwip, as it is an old island. These islands faced cyclic accretion and erosion phenomenon. But their main components still exist. Many small islands also formed in the estuary over the same period, but these were again demolished by coastal erosion. Due to complex hydrodynamic conditions in the estuary, and thereby, the islands changed their position and morphology. Finally, the information revealed from this study will be helpful for estuary management as well as helpful for the Government of Bangladesh to adopt the necessary management plan for sustainable management of the area.

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Conflict of interest

The authors declare no conflict of interest.

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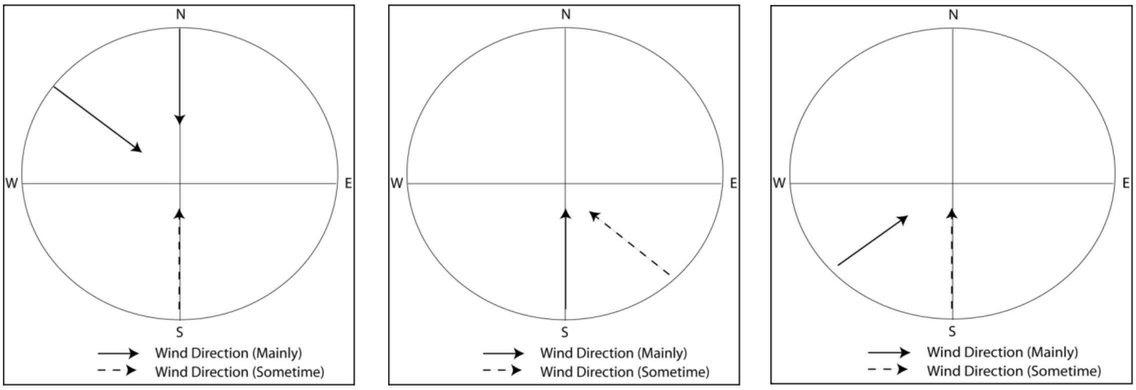
Supplementary



(a) (b) (c)

Figure S1. Wind direction in the study area a) November to February; b) March to May; c) June to October (Data Source: Bangladesh Meteorological Department (BMD)).

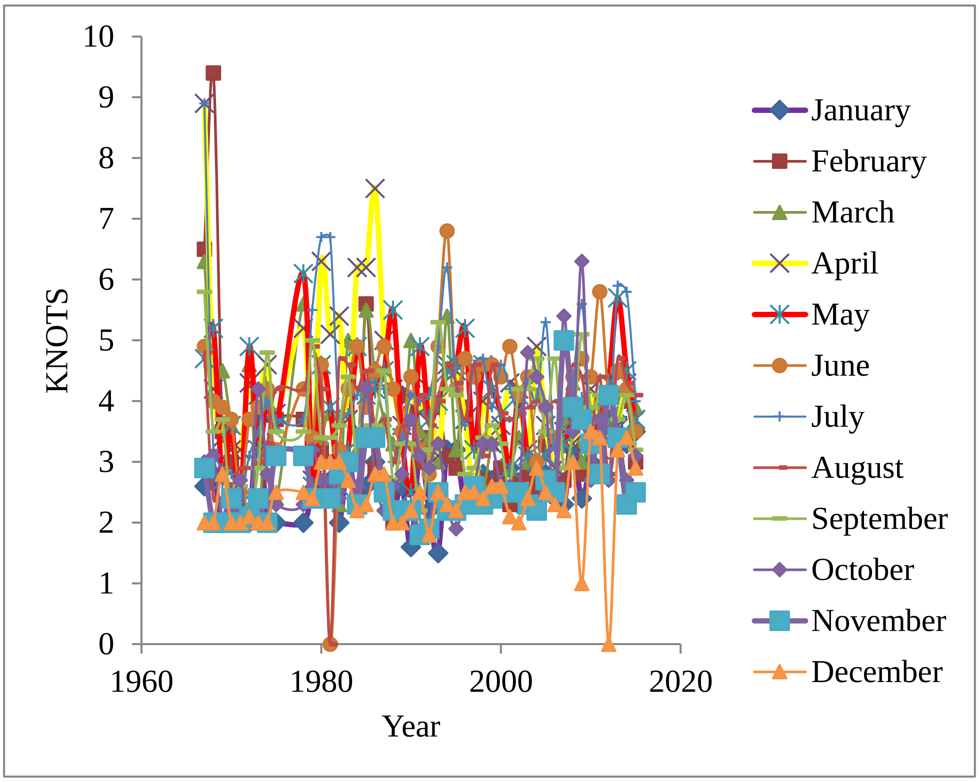


Figure S2. Monthly Wind Speed in the Study Area from 1965 to 2015 (Data Source: BMD).

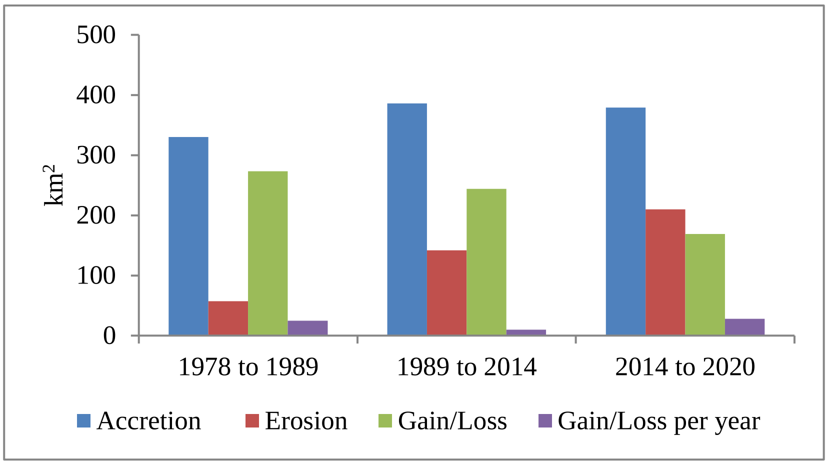


Figure S3. Total erosion, accretion, gain/loss of different islands at different time duration.

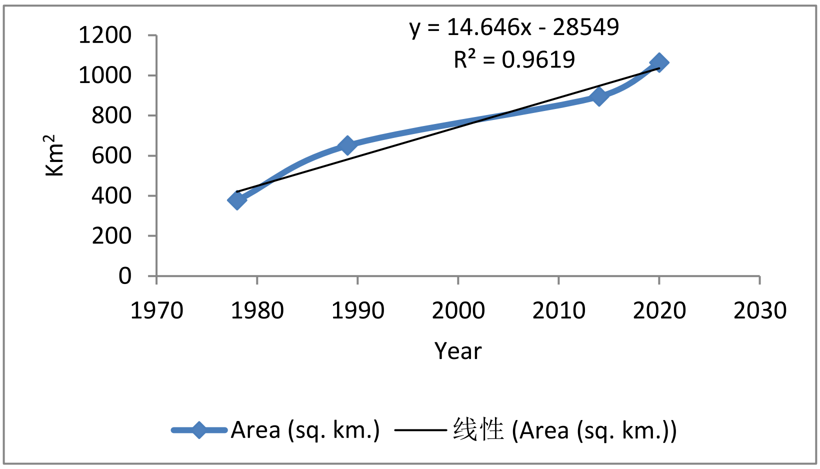


Figure S4. Total area (km^2) of islands from 1978 to 2020 and trend line.

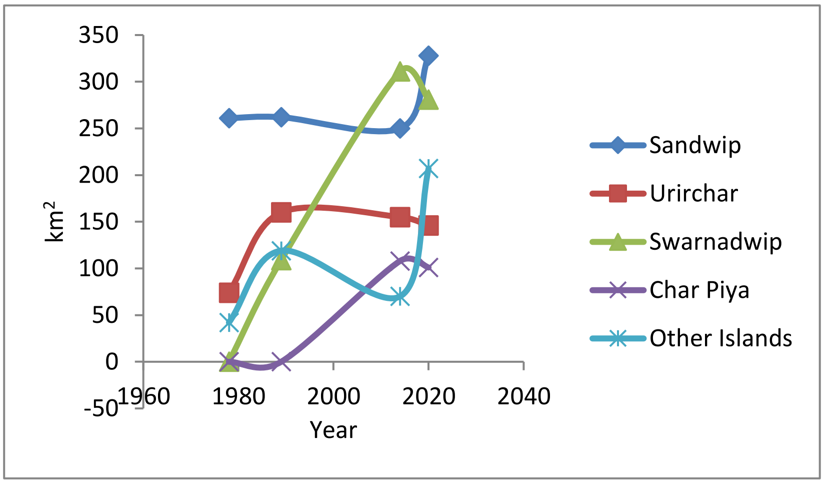


Figure S5. Area (km^2) of different islands from 1978 to 2020.

Table S1. Total erosion and accretion (km^2) of different islands at different times duration.

Duration		1978–1989	1989–2014	2014–2020
Sandwip	Accretion	15	27	85
	Erosion	14	44	7
Urirchar	Accretion	101	81	10
	Erosion	15	(49 + *46) = 86	19
Swarnadwip	Accretion	109	(120 + *46) = 166	19
	Erosion	0	11	49
Char Piya	Accretion	0	108	29
	Erosion	0	0	36
Others Island	Accretion	105	49	179
	Erosion	28	98	42

Note: *during 1989-2014, erosion was taking place in the middle southern part of Urirchar and consequently 46 km^2 land deducted from Urirchar and added to the Swarnadwip by sedimentation within the channel in between Urirchar and Swarnadwip, therefore here 46 km^2 area shown as erosion in case of Urirchar and consequently same was added to the Swarnadwip.

Table S2. Total gain/loss (km^2) of different islands at different time duration.

Year	1978–1989	1989–2014	2014–2020
Sandwip (Gain/Loss)	+1	−17	+78
Sandwip (Gain/Loss per year	+0.09	−0.68	+13
Urirchar (Gain/Loss)	+86	−5	−9
Urirchar (Gain/Loss per year	+7.82	−0.2	−1.5
Swarnadwip (Gain/Loss)	+109	+155	−30
Swarnadwip (Gain/Loss per year	+9.91	+6.2	−5
Char Piya (Gain/Loss)	0	+108	−7
Char Piya (Gain/Lossper year	0	+4.32	−1.16
Others Island (Gain/Loss)	+77	−49	+137
Others Island (Gain/Loss per year	+7	+1.96	+22.83

Note: *(+) gain and (−) Loss.