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Coastal Landscape Development and Dynamics: A GIS-Based Case Study on Char Kasem, Patuakhali, Bangladesh

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Abstract

Bangladesh is a riverine country carrying a massive load of sediment and water, which forms many coastal char-lands in the southern part of the country where these rivers drain into the Bay of Bengal. Considering this state, the coastal char-lands of Bangladesh are highly dynamic as these change their size, shape, orientation, and other physical attributes frequently. Focusing on one of these chars, which is Char Kasem, an isolated coastal char of the Patuakhali district of Bangladesh, spatio-temporal dynamism, stability, shoreline shifting, digital elevation model (DEM), processes shaping the landform, land use-land cover (LULC) change, and overall landscape development of the char is being assessed and evaluated from the year 1984 to 2024. The stability and shoreline shifting of the char are being analyzed by Google Earth Pro data and QGIS 3.16 software, which resulted in the char's stable land declining, as does the shoreline. Elevation models are created using Google Earth Pro software's elevation data, which GPS Visualizer later converts. These elevation models uncover that the higher the elevation, the higher the chance of stability of the char-land and vice versa. The major geomorphic processes shaping the char are being identified through field surveys and quantified by Google Earth Pro software, which indicates that the erosion process outweighs the process of accretion in terms of significance, as 271 hectares of landmass are being eroded while only 46 hectares of landmass is being accreted in forty years (1984-2024). Google Earth Pro, ArcMap 10.5, and QGIS 3.16 visualize the LULC change and landscape development. The analysis implies that landforms of the char are maturing with significant changes as more people settle down, which impacts land use. The size of the char is decreasing steadily, and its ability to thrive is at risk if the present condition continues for an extended period of time.

Subject Areas

Coastal Geomorphology, Geographic Information System

Keywords

Landscape Development, LULC, Stability, Erosion, Accretion

1. Introduction

Coastal landscapes change constantly due to natural phenomena like tides, waves, currents, and human interventions [1]. Thus, these areas are highly dynamic in nature and impact the surroundings in a multi-variate way. Bangladesh is located downstream from the Ganges-Brahmaputra (GB) river basin. This basin carries a massive sediment load and confluences with the Bay of Bengal in the south. The year-round sediment deposition or siltation of the Ganges, Brahmaputra, and Meghna rivers is around 1.8 billion tons [2]. This huge sediment load settles in some areas while transporting due to confluence or a declined carrying capacity, creating mainland detached landforms known as "Char", which can be riverine or coastal. It has been implied that the Meghna estuary zone is part of the Ganges-Brahmaputra delta, building the coastal char-lands right now [3] [4]. The annual erosion rate of these coastal chars is 50 meters to 200 meters per year [5]. The annual gain in these char-lands is 20 km^2 after the erosion and accretion procedures are completed [6]. Coastal islands or char-lands, mainly located in the Meghna estuary zone, exhibit complex geomorphological characteristics leading to unpredictable changes in the landscape evolution [7]. The central coast of Bangladesh undergoes constant transformation due to hydrodynamic processes (erosion, accretion), coastal tides and currents, and counter-clockwise residual flow [8]. Intricate sedimentation processes of the Ganges-Brahmaputra delta are being controlled by continuous deposition and erosion, which shape the overall landscape of the char-lands [9]. The combination of fluvial and tidal processes shapes the dynamic landscapes of Bangladesh [10]. Apart from this, the shoreline shifting of islands and chars occurs more dominantly in the estuary zones due to seasonal floods, sea level rise, cyclones, etc. [11]. Studying these landscapes, like Char Kasem, Patuakhali, is important to understand how coastlines develop and change over time [12]. This knowledge is essential for predicting future changes, such as those caused by sea-level rise, climate change, etc., and designing coastal management plans to promote sustainability. By focusing on Char Kasem as a case study, researchers can gain valuable insights about the region's strengths, challenges, and opportunities [13]. These findings can boost local development strategies and resource management practices in Char Kasem, which can contribute to broader coastal management strategies for Bangladesh and beyond [14].

Char Kasem is an ideal location for studying landforms due to its proximity to the Bay of Bengal. Its modest size allows better visibility of landform processes and growth. Various studies have been conducted on the growth and evolution of coastal landscapes and the socio-economic conditions of people living in various char-lands in Bangladesh. However, there is a lack of studies specifically focused on Char Kasem. Despite its small scale, the char requires a comprehensive study for comparative analysis with other char-lands, allowing policymakers to implement necessary measures. Considering the need, this research study will evaluate various morphological processes, evolution, stability, dynamics, and landscape development of Char Kasem in Patuakhali, Bangladesh. The study's precise objectives are to assess the spatio-temporal dynamism and landscape development of Char Kasem using historical images (1984-2024), and to analyze the processes driving the changes in this char-land.

2. Methodology

2.1. Study Area

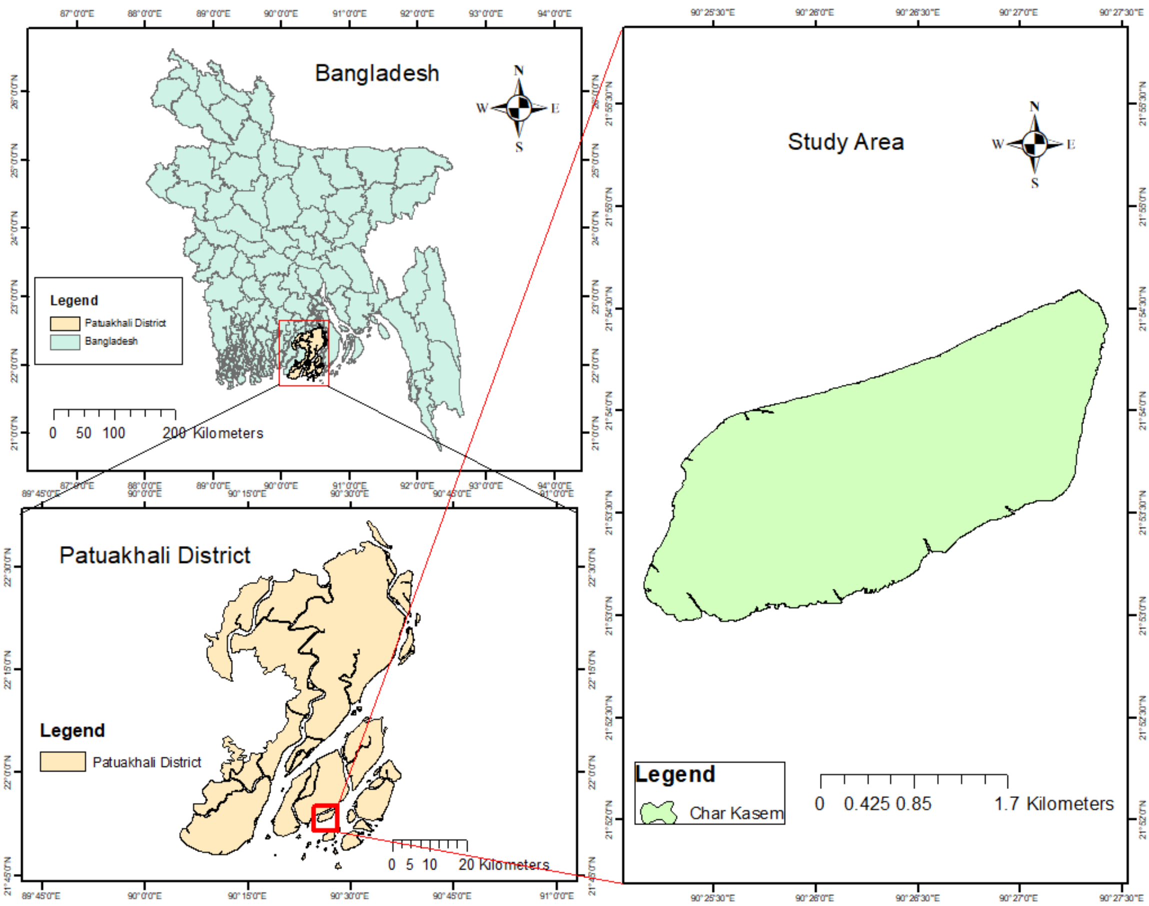


Figure 1. Study area map (Char Kasem).

Char Kasem is located in the Patuakhali district of Bangladesh. It's situated within the Meghna Estuary, part of the Ganges-Brahmaputra-Meghna (GBM) delta. This region is highly dynamic due to the interplay between tidal and fluvial forces, which contributes to the formation of char lands. Char Kasem is about 0.5 km from Rangabali upazila and 15 km - 20 km from the mainland, and the absolute location of the study area is 21˚53'40.48"N, 90˚26'18.18"E (**Figure 1**). The soil at Char Kasem is primarily alluvial, derived from the Ganges-Brahmaputra-Meghna river system. These soils are highly fertile, containing a mix of silt, clay, and sand, which supports agricultural activity. However, they are prone to erosion due to tidal and river currents, storm surges, and saltwater intrusion, which affects soil quality and crop cultivation. Char Kasem experiences a tropical monsoonal climate divided into three distinct seasons, which are: Pre-monsoon (March-May), Monsoon (June-September), and Post-monsoon/Winter (October-February). Pre-monsoon is characterized by high humidity and thunderstorms; Monsoon by heavy rainfall, flooding, and soil erosion; and Post-monsoon/Winter by moderate temperatures, reduced precipitation, and cyclones.

2.2. Data Source

For the completion of the study, two types of data are being collected and used. These include:

2.2.1. Primary Data

Interviews with local people help collect perspectives from people and stakeholders. They possess knowledge of the region, which allows them to comprehend the specific processes, land use patterns, and other distinguishing features of Char Kasem.

Kobo Toolbox is used to conduct a questionnaire survey and gather structured data from the local community. This survey specifically collected data regarding land use, environmental changes, and socio-economic indicators.

Direct observations and data gathering were conducted on-site to evaluate the physical and environmental properties of Char Kasem.

Surveys are conducted to gather comprehensive data on the many factors that impact Char Kasem, such as land use, environmental changes, and local practices.

2.2.2. Secondary Data

An assessment of satellite images (Airbus, Maxar Technologies, Copernicus, Landsat) of Char Kasem from 1984 to 2024 using platforms such as Google Earth Pro is being completed to identify temporal variations in land cover and geomorphology.

The utilization of Geographic Information Systems (GIS) and Digital Elevation Model (DEM) data retrieved from Google Earth Pro facilitates the analysis of spatial data, including changes in elevation and landform dynamics.

A comprehensive examination of published data and literature is conducted to offer contextual and foundational knowledge, therefore facilitating the analysis and interpretation of the gathered data.

Reviewing published literature is the process of identifying this research's overall methodology. The validation process also involves this literature.

Investigating the geomorphological and socio-economic dynamics of Char Kasem is being accomplished via the utilization of a rigorous approach that combines primary and secondary data sources. In this process, the collected data from various sources are analyzed to arrive at the result.

Considering these, the usages of primary and secondary data are followed by the objectives, and combinations of these data sources are used when necessary.

2.3. Methods

In order to accomplish the objectives of the study, these methods are being followed (**Figure 2**):

1) Satellite imagery from 1984 to 2024 was analyzed to assess for land use-land cover changes, shoreline shifting, and landform development.

2) The photographs were processed and analyzed using QGIS 3.16.16 and ArcMap 10.5 to achieve the required outcomes. The processing includes georeferencing, reprojection to EPSG:32645 (local projected coordinate system), and resampling with bilinear interpolation to reduce analytical errors. Raster cell size was standardized to 30 meters for all analyses.

3) Char Kasem's topography was analyzed using a digital elevation model (DEM). The collected elevation data was first generalized using 'Fill' tool of ArcMap, and after that, a complete category development was completed to understand different elevation zones and their relations.

4) Field observation was conducted to gain an understanding of the geomorphological processes that are currently taking place, and that's why direct observations are taken in the field. These observations, which are made in real-time, provide data on how natural and human-induced variables are changing the landscape. Apart from that, these are used for further classification and validation.

5) A structured survey is being carried out among the local population to gain insights into the local community's perspectives and experiences regarding the changes that have taken place in Char Kasem.

6) Quantification is being conducted using Geographic Information System (GIS) tools. Geographic Information System (GIS) technologies, notably Google Earth Pro and QGIS, are utilized to quantify and evaluate the data gathered through field observations and surveys. These instruments help determine the extent of changes and recognize trends in the geomorphological processes that are taking place.

7) Evaluation of Software for Geographic Information Systems (GIS) is applied to evaluate the development of the terrain in Char Kasem. This category includes mapping the number of changes to LULC, identifying trends, and comprehending the ramifications of these changes on the community and the environment in the near neighborhood.

8) Shoreline digitization, landscape development, and land use-land cover classification were performed manually on a preferred scale to identify features. Shoreline's tracing was completed by visually identifying the water-land interface. Landscape development analysis was performed using the aforementioned technique.

Whereas LULC classes were delineated based on tone, shadow, color, orientation, field observation, and other contextual cues. "Stable land" was identified as areas showing no visible change between imagery from 1984 and 2024. To estimate operator error, 10% of the digitized polygons were independently re-digitized, yielding a mean positional error of ±3 meters (RMSE = 4.2 meters) for linear features. Classification accuracy based on 75 field verification points was 88%, with a Cohen's Kappa coefficient of 0.83, indicating strong agreement between digitization and ground truth data.

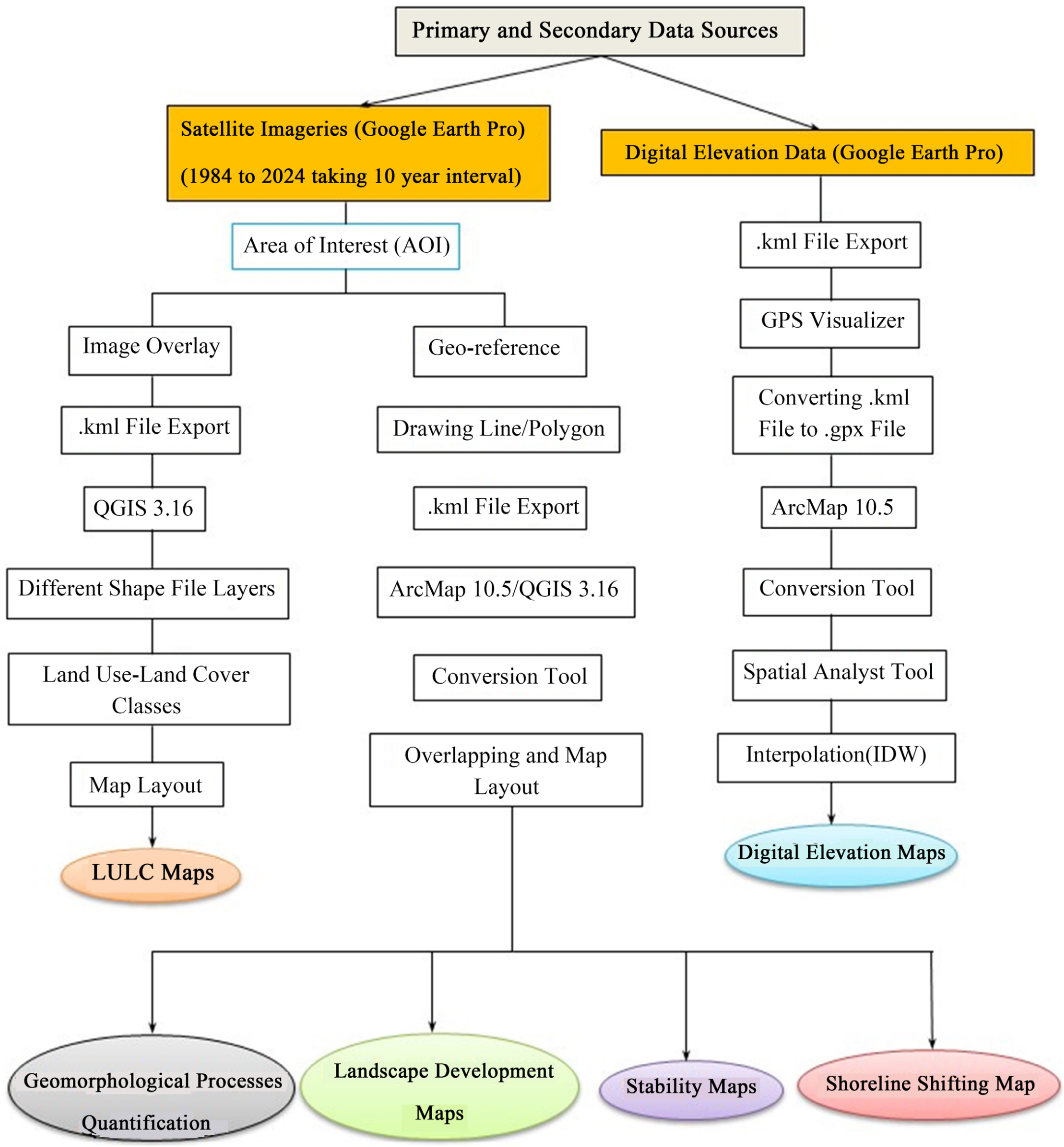


Figure 2. Methodological framework of the study.

9) All these data and procedures will produce important data and maps (e.g., shoreline shifting, LULC, etc.) that are crucial for attaining this study's objectives.

10) Google Earth Pro imagery has horizontal errors up to ±3 m, and the DEM

vertical accuracy is about ±0.8 m RMSE. Since elevation changes on Char Kasem were near 1 m, this limit precisely detects subtle terrain shifts. These uncertainties were accounted for in the analysis.

3. Results and Discussion

3.1. Morphological Stability of Char Kasem

Char Kasem, a small coastal island in Bangladesh, has been subject to significant changes over the past forty years. The island has experienced wave action and silt buildup, which have led to significant changes in its stability. The ten-year interval between 1984 and 2024 reveals the island's stability. The char-land has undergone several significant transformations, including erosion and deposition, as well as stable land. In 1984, the circumference of Char Kasem measured 14.9 km, while its total size was 867 hectares (**Figure 3**). In 1994, the circumference measured 13.9 km, and its size amounted to 855 hectares. The land area dropped by 12 hectares during this decade. Char Kasem's stable land during this period is 839 hectares, with a perimeter of 14.7 km. However, the land area has significantly decreased, with 146 hectares lost in this decade. The stable land over this time span is 698 hectares with a circumference of 13.5 km. From 1984 to 1994, the island's stability remained relatively steady, despite minor changes in its size and shape. The stability of the land held greater significance during this period. The rate of erosion and accretion was nearly equal in 1984 and 1994, but changed to a higher erosion rate and a lower accretion rate in 2004. During these periods, the char-land was home to a variety of small to medium-sized tidal creeks, but 2004 saw the emergence of more mature creeks. In 2004, the char's shape began to resemble the shape of the island in 2024. The char was taller in 1984, but it became fatter starting in 2004, resulting in the loss of the upper and lower portions from 1984. This dramatic shift has far-reaching implications for the ecology, flora, succession phases, ecosystem, and human lifestyle trends. Sedimentation, or the formation of new regions, took place in both the northern and southeastern sections of the char. The erosion in the eastern and southwestern parts of the char wiped away landmasses. The amount of land degraded and added during this decade is approximately equivalent to that of the preceding two decades. In 2014, the char had a total area of 709 hectares and a perimeter of 13.8 hectares, resulting in a loss of 23 hectares of landmass and 2.3 kilometers of perimeter. The loss of land has significantly affected the ecology and ecosystem of the char, leading to its deterioration. Erosion was the main cause of land removal from the northeastern and southern regions of the char, while accretion occurred on the northern portion. In 2014, the perimeter of the char was 11.5 km, and its total land area was 686 hectares. However, by 2024, the circumference had increased to 13.3 km, while its total land area had decreased to 642 hectares. The rate of displacement is significantly greater than the rate of deposition, with the northern region of the char being the primary site of accretion. The territory of Char Kasem was 867 hectares, with a perimeter of 14.9 kilometers in 1984, and now has a perimeter of 13.3 kilometers and a total area of 642 hectares (Figure 3).

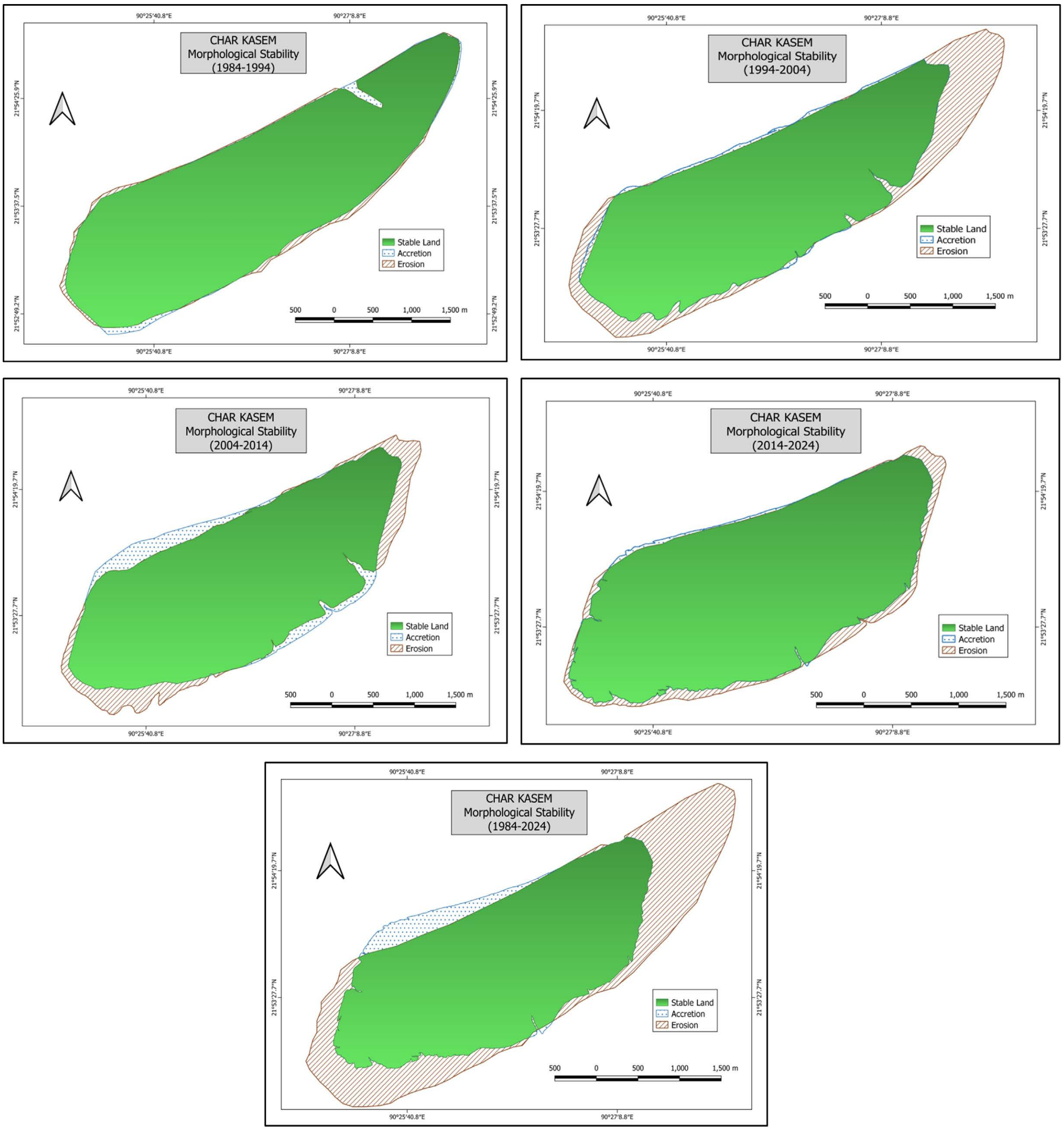
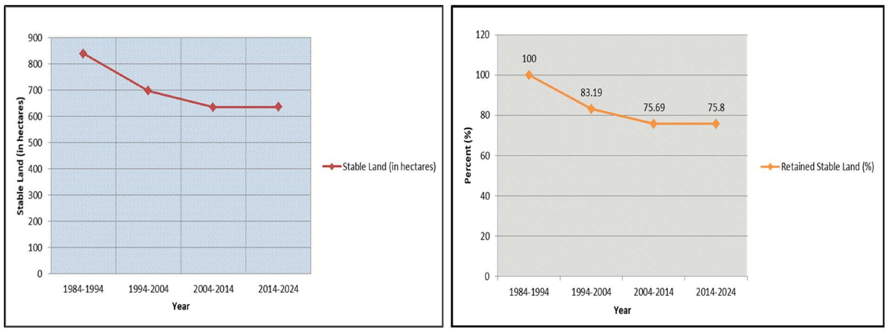


Figure 3. Morphological stability of Char Kasem (1984-2024).

This represents an extensive negative shift within the forty-year time frame, with 225 hectares of land forfeited and 1.6 kilometers of perimeter lost. The total stable area from 1984 to 2024 is 597 hectares, with a perimeter of 13.8 kilometers. Over the first decade (1984-1994) of the analysis, 839 hectares of land remained stable (Figure 4(a)). From 1994 to 2004, the stable area decreased to 698 hectares. From 2004 to 2014, it decreased to 635 hectares. Between 2014 and 2024, the stable land increased to 636 hectares. The stability of Char Kasem has significantly declined over the past three decades, with a total of 597 hectares of stable land remaining. In the period of 1984 to 1994, considering the retention of stable land 100%, from 1994 to 2004, it had fallen to 83.19%, indicating a significant loss (Figure 4(b)). From 2004 to 2014, the retention of stable land reached 75.69%, a decrease of 24.31%, and finally, from 2014 to 2024, it reached 75.8%. This indicates a significant decline in the stability of Char Kasem. Although there has been some improvement in land retention over the past decade (2014-2024), this will be insignificant if erosion continues to outpace sedimentation in the future (Figure 4(b)).



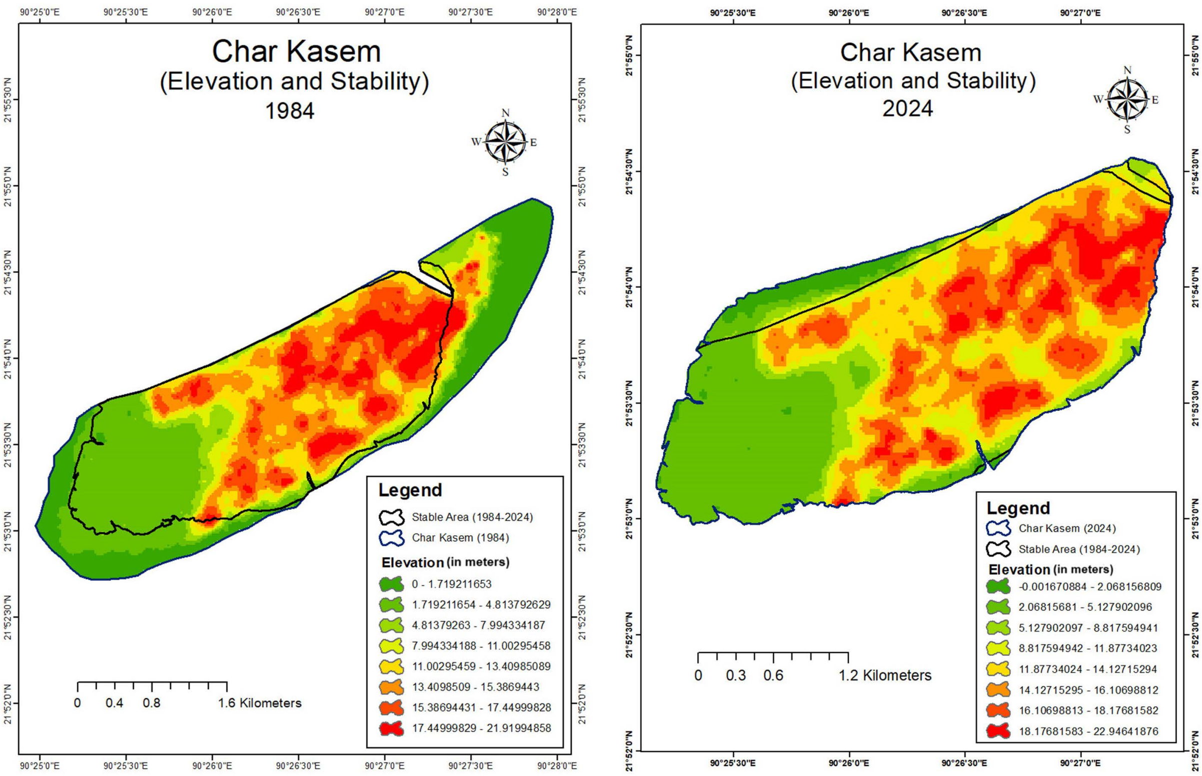
(a) (b)

Figure 4. (a) Stable land of Char Kasem (1984-2024) and (b) Retained stable land of Char Kasem (1984-2024).

The enormous amount of land loss over the course of forty years has significantly altered the environmental state of the char. The stability of the char depends on the net rate of erosion and accretion, which have shaped the character of the char from its inception. Land stability increases the likelihood that coastal landscape size and shape will persist. As the stable land of Char Kasem underwent significant changes from 1984, so did the size and shape of the char itself. The previous phases led to a significant decrease in the quantity of stable land, which in turn determines the future of the char. If the stable area decreases significantly in the future, the char may face significant challenges regarding its sustainability. In conclusion, Char Kasem's stability has declined since its inception. This impacted the char in changing the size and shape of the char-land. Not only this, but the environment and the people living in that char face a great deal of issues, as the char's declining stability forces the erosion event to occur randomly all over the char, creating major problems.

3.2. Digital Elevation Model (DEM) and Stability

Portrayal of the Earth's topographical surface devoid of any natural and anthropogenic surface features is known as DEM [15]. The elevations are not uniform over the entire char; rather, different parts of the char have varying levels of elevation. In the year 1984, the shoreline of the char had the lowest elevation, which was somewhere between 0 and 1.7 meters. This was the lowest elevation that can be seen (Figure 5(a)).



(a)1984 (b)2024

Figure 5. Relationship of digital elevation model and stability of the char-land (a: 1984 year; b: 2024 year).

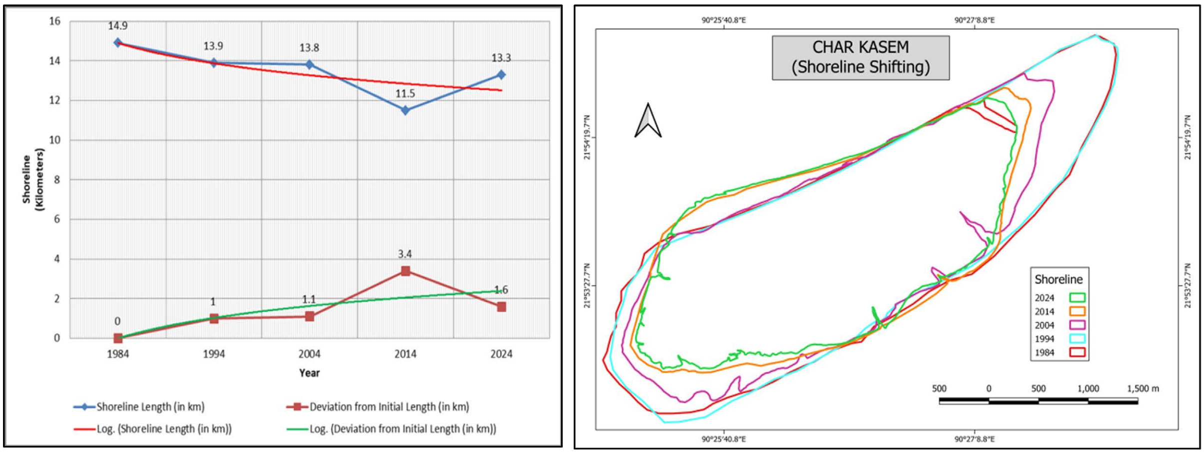
After that, the lower part of the char, which is bare and some people inhabit in that area, comes with the elevation of 1.7 to 4.8 meters. Following that, a very small section of land that is an outcirclement of the previous elevation profile is being shown with an elevation ranging from 4.8 to 7.9 meters. Alongside the elevated zones that came before, the char-land that ranges in height from 7.9 to 13.4 meters may be found scattered throughout the area. Only a very minor section of the char was occupied by the region that contained an elevation ranging from 13.4 to 15.3 meters. The subsequently raised zones, which range in height from 15.3 to 17.4 meters, were primarily situated in the middle of the char (Figure 5(a)). As a last point of interest, the region with 17.4 to 21.9 meters in elevation was primarily situated in the upper-middle section of the char as well as the center half of the char. This was the highest elevated zone of the char. The higher elevated zone of 1984 seems to be the stable land that can be found today. The stable land doesn't contain the lowest elevated zone of that time rather except for the lower part of the stable land; all of the char represents mainly the high elevated area especially the elevation ranging from 15.3 to 21.9 meters (Figure 5(a)). In 2024, the lowest elevation is up to 2.06 meters, which can be seen on the edge of the char (Figure 5(b)). Then the char with an elevation of 2.06 to 5.13 meters can be seen on the lower part of the char. This is the zone where people of the char are living, and different shrimp cultivating zones are also located here. The elevation of 5.13 to 8.8 meters can be in a small area of the char. The elevation of 8.8 to 14.12 feet covers a good amount of area from the upper part of the people-inhabited zone to the top of the char-land. The zone containing the elevation of 14.12 to 16.18 meters is located in the middle part of the char as well as the upper part encircling the highest elevated areas. The highest elevation of the char is 22.9 meters, which covers a significant part of the char. This is an increase of 1 meter in elevation from 1984 to 2024. The stable areas don't contain the lowest elevated zones. The lowest elevated zones are prone to erosion and may not exist in the near future, or a major part of this will get washed away. Meanwhile, the higher elevated zones of the char will be relatively safer in consideration of other low-lying zones. The inhabited zone at the bottom of the char is also a safer place as it's in stable condition; but the safest places are the highest elevated areas, which are located in the middle eastern part of the char-land (**Figure 5(b)**).

Therefore, based on these situations, it can be concluded that the elevation has a significant impact on Char Kasem's stability: "The higher the elevation, the higher the chance of stability of the land, as well as the lower the elevation, the less chance of stability of land".

3.3. Shoreline Shifting

Shoreline shifting is described as the longitudinal shift of the coastline position as time goes on, impacted by a mix of natural events such as wave motion, tidal currents, sediment supply, and human interference that modify coastal dynamics [16]. The shoreline of Char Kasem in 1984 was 14.9 kilometers, which reduced to 13.9 kilometers in 1994 (**Figure 6(a)**). This is a huge change in shoreline as the deviation is 1 kilometer. In the year 2004, the shoreline length was 13.8 kilometers, which can be considered a minor change in shoreline, as the shoreline length in 1994 was 12.9 kilometers. So, the difference in shoreline change was 0.1 kilometers. The deviation from the initial length is 1.1 kilometers here. The shoreline length was 11.5 kilometers in 2014, which is the highest drop in the curve, as the deviation from the initial length is the highest, resulting in a 3.4-kilometer reduction of shoreline. Therefore, the char experienced a massive amount of change. This must have a long-lasting impact on this coastal char. Finally, the deviation from the initial shoreline length is 1.6 kilometers in 2024. This indicates a rise of the shoreline of 0.5 kilometers. The shoreline length is now 13.3 kilometers. This also shows an increase in total shoreline compared to the shoreline of 2014. The trend of shoreline length is shown through a logarithm, which indicates the negative trend, meaning that the shoreline of Char Kasem is decreasing with time. The trend line of deviation from initial length also shows that the reduction of shoreline is rising with time (**Figure 6(a)**).

So, the shoreline length will decrease with time if no massive changes in sedimentation occur and a high rate of erosion decreases. Analysis indicates that the shoreline shifting is continuous, and the changing pattern is highly dynamic, and the middle part of the char from 1984 is now the stable land. The eastern part of the shoreline has shifted to the west and downward, reaching the present condition. There is a significant shift of shoreline in the northern part, which was located relatively downward in 1984. Meanwhile, the bottom part of the char is gradually lessening over 40 years since 1984.. The southeastern part of the char hasn't changed a lot, considering the other parts. All over the char different tidal creeks have formed and impacted the shoreline massively (**Figure 6(b)**).



(a) (b)

Figure 6. (a) Quantification of shoreline shifting (1984-2024); (b) Shoreline shifting of Char Kasem (1984-1994).

The shoreline has seen a favorable shift in the northern central area of the island, resulting in a significant increase in shoreline. However, all other zones of the island have seen a decrease in shoreline, which indicates negative shifting. If this ongoing process of negative shifting persists, the island of Char Kasem will gradually erode and eventually become submerged in the sea.

3.4. Landscape Development

Char Kasem can be found in the western part of the Meghna estuary. To put it another way, the Meghna estuary is the region in which all of the landmasses are either being produced or being transformed by the silt that is being transported by the GBM river system, as well as the erosive strength of water. Before reaching its current form, the landscape of Char Kasem underwent a lengthy process leading up to its current appearance. The enormous amount of sedimentation that occurs in the Meghna estuary, as well as the increased erosive strength of tides and currents, had a significant impact on the area's orientation, position, size, and form. From 1984 to 2024, a range of natural and anthropogenic events shaped the coastal char-land, leading to its current state. The terrain transformation is still taking place and will continue to do so in the years to come. The landmasses around the char also changed their size, shape, position, and orientation. During this time frame, different types of emerging and submerging char-lands can be observed. Some of the char-lands are freshly formed; some are getting bigger by accumulating more sediment, while others are getting washed away by greater erosive power (**Figure 7**).

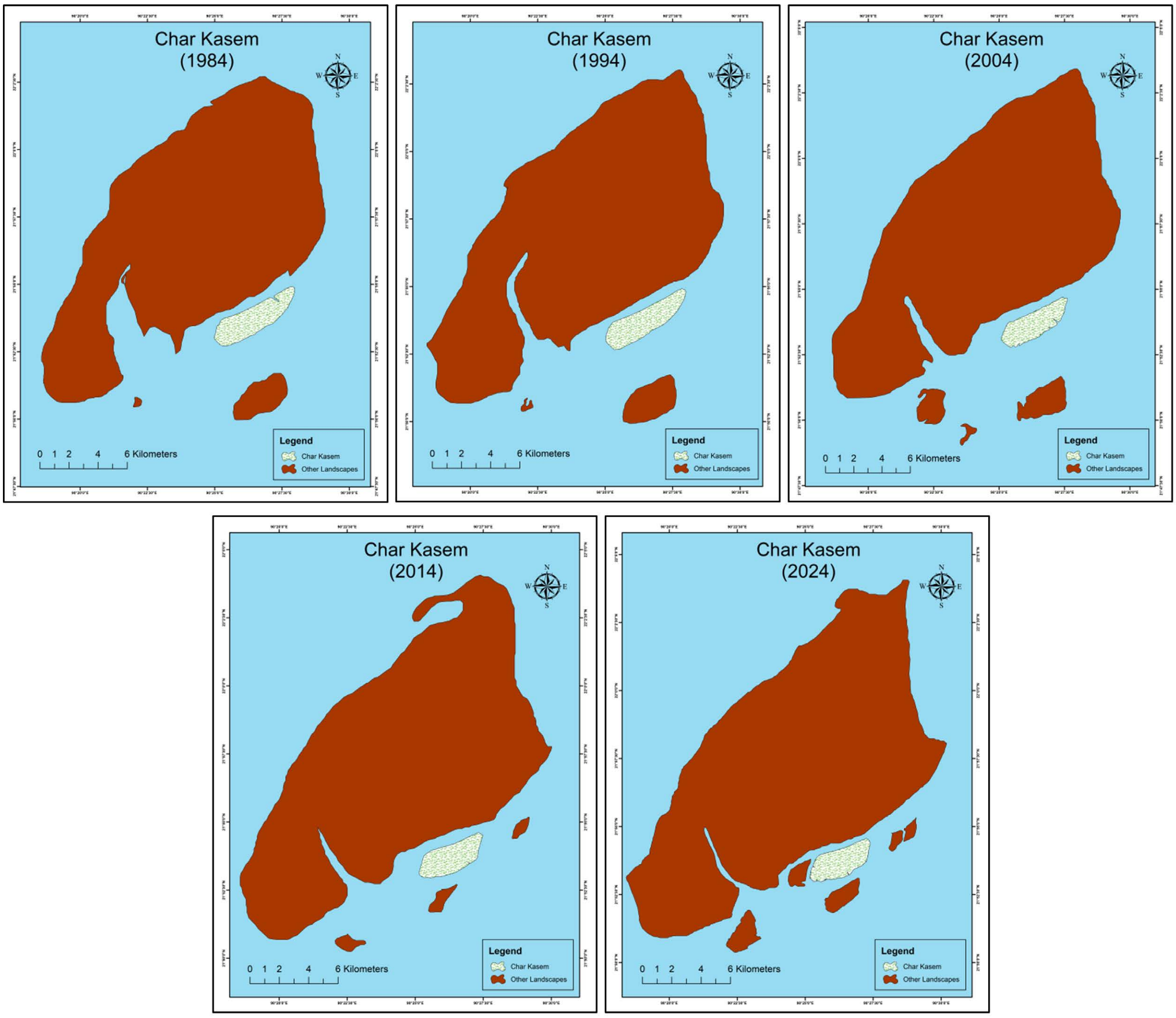


Figure 7. Landscape development of Char Kasem (1984-2024).

Char Kasem has always stayed close to the largest char around it, which is Rangabali. Rangabali, an upazila in Patuakhali district, has been staying with Char Kasem since its inception. During the forty-year time frame, a variety of chars emerged, some submerged, and others rose to the surface. There were two small landmasses around Char Kasem in the year 1984, which stayed constant until 2004, when a new landmass emerged. Some of the small landmasses drifted away or submerged with the replacement of the previous three landmasses with new three during 2004 to 2014. In the year 2024, the number of small landmasses around Char Kasem has reached five, which was three previously (Figure 7). The smaller landmasses were far away from Char Kasem in the earlier decades of 1984, 1994, and 2004. These started to form or emerge in close proximity after 2004, and this process continues to this day. The biggest char (Rangabali) and Char Kasem have seen severe erosion due to the direct impact of water and other physical phenomena. Rangabali has been eroded significantly, and the shape of the landmass has changed, especially in the zone where it is located, the closest to Char Kasem. The erosion level in this specific region of Rangabali may be readily observed, as it has eroded inward in a crescent shape. Char Kasem has also changed its size and shape due to more prominent erosive actions. In 1984, the char elongated, but its length significantly decreased from 1994 to 2004. After that, the char became fatter than before, but the amount of landmass loss gave it its recent form. Sediments from Char Kasem and Rangabali, as well as the sediment-carrying basin, create the surrounding small landmasses. For this reason, the small landmasses are located close to Char Kasem and Rangabali. A small landmass is located just below Char Kasem (**Figure 7**). This suggests that Char Kasem's erosion and deposition of this eroded landmass are forming the majority of this new small landmass.

3.5. Land Use and Land Cover (LULC) Change

There are a total of 11 types of land use and land cover across Char Kasem, considering the time frame of 1984-2024, which include tidal creeks, natural mangrove vegetation, low-lying wetted zones commonly referred to as the intertidal zones, barren lands, built-up areas, designated areas for salt cultivation, shrimp cultivation zones, agricultural zones, ponds, canals, and unpaved roads used by smaller transport and people. These fluctuated from time to time. In 1984, significant tidal creeks were evident, and a subtle intertidal zone could be seen in the eastern part of the char. The middle section of the human-inhabited zone contains barren land, also visible as dunes (**Figure 8**). During that period, the formation of both landforms and vegetation was in its early stages. Given the limited number of dwellings in 1984, we can infer that many individuals had recently migrated to the char. During that period, most of the char's territory remained devoid of human interference. Shrimp cultivation, an entirely new form of land utilization, was not present in 1984. The distribution of tidal creeks in 1994 exhibited significant disparities, accompanied by a decline in their overall magnitude. The vegetated environment remains mostly unchanged, with very slight alterations. Low-lying wetted zones extending from the shoreline encircle the char, except in specific regions. In 1994, unpaved roadways interspersed with other land uses enhanced accessibility. In 2004, the mangrove-vegetated region of the char predominantly featured tidal creeks. The erosion of the char is responsible for the reduction in the vegetated area. The char's eroded section has formed a comparatively larger, lower-lying wetted zone encompassing the char, leaving only a tiny portion. The increasing prominence of human involvement has coincided with a notable decline in barren land. The distribution of unpaved roads within the char indicates their use for many land purposes, facilitating the transportation of commodities and enabling individuals to travel to different destinations. In former years, tidal streams were predominantly located inside vegetated terrestrial regions. However, in 2014, most tidal creeks were found in the lower section of the char, close to human settlements. At present, erosion has eroded a significant portion of the char-land, decreasing the vegetation-covered surface area compared to previous decades. A low-lying wetted zone encompassed the char, except for the northeastern region. The extent of barren land has significantly diminished due to the increase in human population and the subsequent utilization of this area for diverse reasons (**Figure 8**).

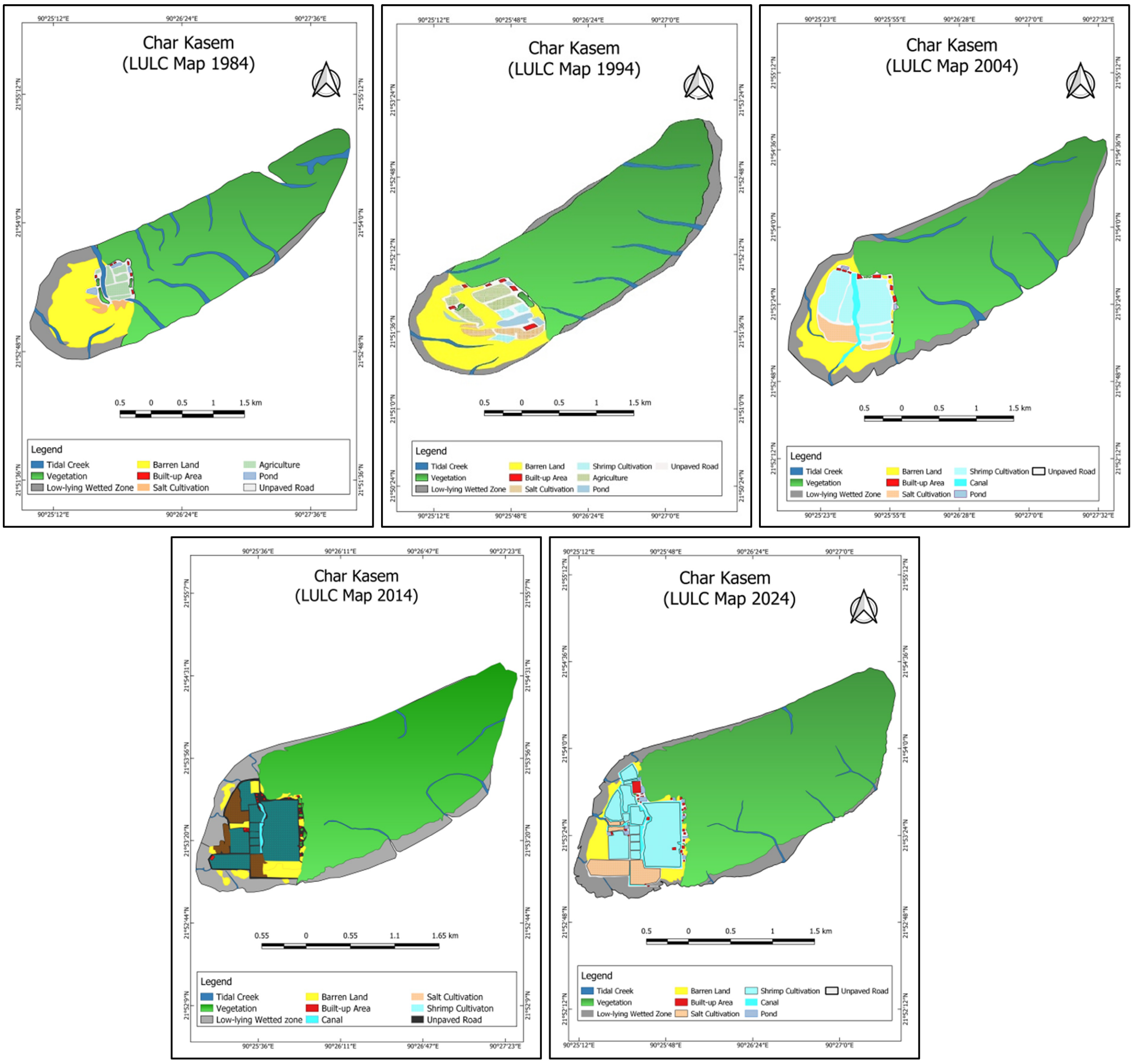


Figure 8. Land use and land cover (LULC) change detection (1984-2024).

In 2024, tidal creeks are now more mature and have branches. The erosion of the char has led to a decline in the total area of vegetation. Intertidal zones are now located surrounding the char from the shoreline, except for the upper northeastern part. Barren land also decreased significantly, while the unpaved roads have also become more accessible and extensive (**Figure 8**).

3.6. Driving Processes for Char Development

The formation of coastal landscapes is not a spontaneous occurrence but rather the result of several processes that contribute to both their emergence and submergence.

The shape and river flow into coastal and estuarine areas, tide range, and wave impact primarily influence the shape and arrangement of the shore and estuary [17]. The key factors that control the sediment distribution process in an estuary are the properties and amount of the sediment, the tidal range, the waves, and the shape and geometry of the estuary [16] [18]. Erosion and accretion primarily shape the coastal chars of Bangladesh. Thus, these two major geomorphic processes—erosion and accretion—occur synchronously, shaping the terrain of Char Kasem.

Table 1. Erosion and accretion of Char Kasem (1984-2024).

Year	Erosion (ha)	Accretion (ha)	Net Erosion/ Accretion (ha)	Erosion Rate/Year	E%	Accretion Rate/Year	A%	Stable Land (ha)
1984-1994	28	16	−12	2.8	3.2	1.6	1.9	839
1994-2004	157	11	−146	15.7	18.4	1.1	1.3	698
2004-2014	74	51	−23	7.4	10.4	5.1	7.2	635
2014-2024	50	6	−44	5	7.3	0.6	0.9	636
1984-2024	271	46	−225	27.1	31.3	4.6	5.3	596

Source: Google Earth Pro and USGS, compiled by authors, 2024.

Table 1 presents the comprehensive status of the erosion and accretion phenomena that have been taking place on the char from 1984 to 2024. In addition to these factors, calculations are being made for net erosion/accretion, erosion rate, accretion rate, stable land, percentage of erosion compared to the previous decade, and percentage of accretion compared to the previous decade. The primary observation is that the erosion process is significantly noticeable, as the net erosion/accretion is consistently negative throughout the course of four decades as well as for the entire timeframe.

According to the bar graph (**Figure 9**), there was no net increase in the amount of sedimentation during the whole period. Instead, erosion was the dominant process in each decade. Over a span of four decades, the period from 1994 to 2004 saw the most significant net erosion, resulting in the loss of 146 hectares of charland. Conversely, the period from 1984 to 1994 had the lowest net erosion, with only 12 hectares being lost. The net erosion was 23 hectares between 2004 and 2014, which converted to 44 hectares between 2014 and 2024. Therefore, it may be inferred that the net erosion does not exhibit a definite pattern, but the erosion process itself is rather modest considering the maximum amount of net erosion. From the year 1984 to 2024, the total amount of net erosion is 225 hectares, while the amount of net accretion is zero. This indicates that the char has lost a huge amount of its landmass in this period of time, while it failed to gain net landmass, which is very crucial for any coastal landscape's development and stability. When evaluating the quantity of land that is not prone to alterations, there is a noticeable loss in stability during the past four decades (**Figure 9**).

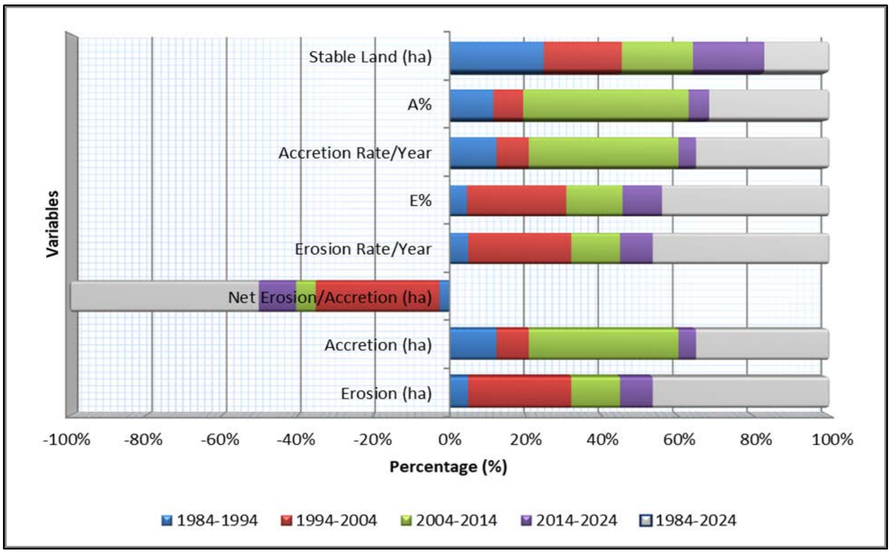


Figure 9. Erosion and accretion-related variables of Char Kasem (1984-2024).

The percentage of erosion and accretion doesn't reveal the exact trend of the processes working on the char. Hence, a comprehensive analysis of the net percentage of the processes has been done. The net percentage indicates a significant erosion process over the four decades (**Figure 10**). The net percentage is −1.3% in the first decade and decreases to −17.1% in the second decade, showing a substantial shift. From 2004 to 2014, the net percentage became −3.2%, and in the final decade, it became −6.4%. The graph is rising in some periods while dropping in others. The gap in the magnitude of the erosion and accretion processes is minimized in some stages, but overall, erosion still dominates the whole scenario. The graph doesn't follow a specific trend, but the pattern is sinuous.

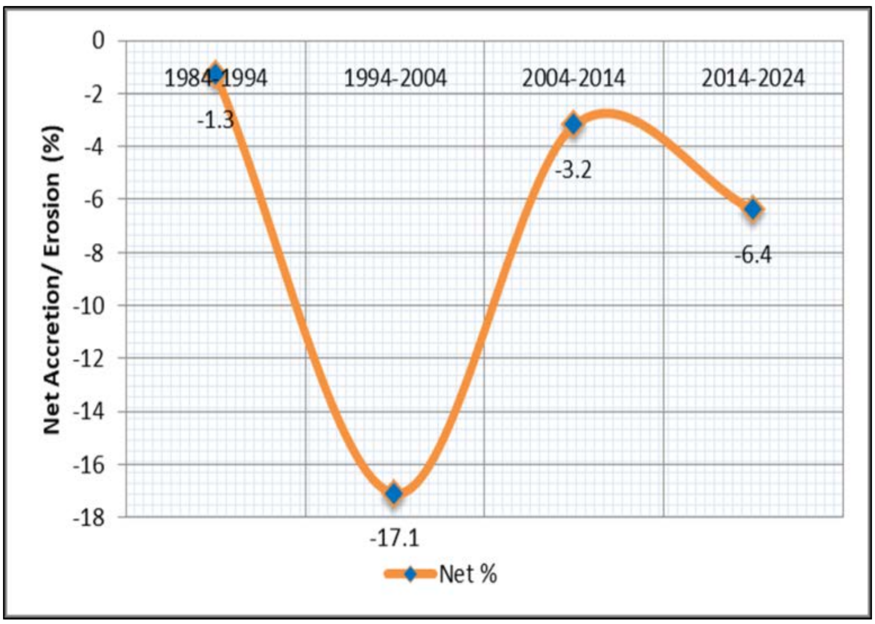


Figure 10. Net percentage of working processes.

This graph suggests that Char Kasem experiences very little accretion and high level of erosion (**Figure 10**). This signifies that the char-land is exceedingly susceptible to erosion, and the future condition of the char remains ambiguous. In this specific char-land, the erosion process is more significant than the accretion process. It highlights the susceptibility of the char to erosion in the near future. This is a critical problem, as the presence of the char is essential for both the residents and the ecological balance of the char.

4. Recommendations

1) Implementation of Integrated Coastal Zone Management (ICZM) to balance ecological sustainability and socio-economic growth.

2) Regular monitoring and assessing coastal changes using remote sensing and GIS technologies.

3) Implementation of sediment management (breakwaters, gyrones, spurs, river training, porcupines, bandals construction to maintain the char-land by reducing erosion while enhancing deposition.

4) To protect the community, cyclone shelters, early warning systems, and coastal defenses should be built, while prioritizing climate change mitigation techniques like greenhouse gas reduction and renewable energy.

5) Integration of local livelihoods into coastal management plans for sustainable agriculture (tolerant variant usage, crop rotation, seasonal farming, intercropping, zero tillage farming, etc.), aquaculture, and eco-tourism.

6) Restoration of natural habitats and biodiversity has to be ensured by a governing body.

7) Developing and enforcing clear regulations to govern human activities and managing haphazard urbanization.

8) Conduction of training and micro-financing for capacity building.

5. Conclusion

Char Kasem, a coastal char-land in Bangladesh, is primarily influenced by natural phenomena like accretion, erosion, tidal action, and river dynamics, while human activities like agriculture and construction contribute to minor changes. The study reveals that the char's landscape changes due to varying degrees of erosion and accretion rates, as well as changing patterns in land use and land cover. The stability and shoreline of Char Kasem have been decreasing over time, indicating high vulnerability, but there has been a recent slowdown. The study emphasizes the need for sustainable coastal management strategies that target climate change susceptibility. Inadequate human activity management could worsen environmental deterioration and increase char-land instability. Implementing effective sediment management, restoring ecology, and engaging the community can improve the stability and resilience of Char Kasem. Apart from that, a comprehensive interdisciplinary strategy combining geographical, ecological, and social perspectives shall be developed for equitable development and preservation of Char Kasem.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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