Geospatial Analysis of the Coastline Changes in the Southwestern Belt in Sri Lanka.

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ABSTRACT

Coastal morphological changes result from a dynamic interplay between natural processes and human activities. The coastal area of Habaraduwa DSD, located on the southwestern coast of Sri Lanka, has undergone morphological changes primarily due to erosion and sedimentation. This research aims to use geospatial techniques to identify these coastal morphological changes of Habaraduwa DSD. Accordingly, this study will identify spatial and temporal shoreline changes (2006-2022) and the land use changes in Habaraduwa DSD from 2008 to 2023. Secondary data were mainly obtained from Google Earth Pro and LUPPD. The Digital Shoreline Analysis System (DSAS) version 5 software was employed to analyze shoreline changes using the NSM, SCE, and EPR parameters. The studies showed that, according to the NSM parameter, the shoreline experienced the highest erosion value of -42.08 meters from 2006 to 2023. The maximum EPR value recorded was 1.67 m/y, while the minimum was -2.63 m/y. Furthermore, an analysis of land use in the Habaraduwa DSD from 2008 to 2023 shows a substantial increase in built-up areas. In 2008, the built-up areas covered 17.83 square kilometres, accounting for 36.49% of the total land area. By 2023, this expanded to 29.25 square kilometres, representing 59.86% of the total land area. This research highlights that the coasts within the Habaraduwa DSD have experienced significant morphological changes, including coastal erosion and extensive land use alterations. The study also underscores potential future inundation areas due to the rising global sea level, emphasizing the need for sustainable coastal management.

Keywords: Coastal Dynamics, Coastal Erosion and Deposition, Land Use

Introduction

A coastal zone in any country can be defined as the interface between land and water (Ahmad, 2019; Adade et al., 2021). "Coast" is used to talk about the parts of land bordering seas or oceans, as well as islands scattered around the earth. Coasts are generally defined as unstable landscapes due to constant changes in soil, marine erosion, and the action of sedimentary deposits. The coastal zone is a highly dynamic zone being influenced by both human and natural processes. Human activities such as resource extraction, industrialization, tourism, and urbanization greatly influence the coastal zone's environment. Unplanned expansion of the tourism sector, unsustainable development of urban infrastructure, waste disposal, shipping, transport, and local power plant discharges are some of the other activities that negatively influence the coastal ecosystems. Coastal areas are very important for human beings, as they witness cultural and economic exchanges between different nations. Most of the big cities with famous harbors around the world are situated in coastal areas. About 40% of the global human population and 50% of marine life live in low-lying coastal zones with elevations less than 10 m above the mean sea level (Digest, 2022). Due to abundant natural resources, urbanization and population rapidly increase in coastal areas. Various developmental projects are installed in the shoreline areas, placing great pressure on them and leading to diverse coastal hazards like sea erosion, seawater intrusion, coral bleaching, shoreline change, etc.

The wearing of land surfaces and the loss of beach, shoreline, or dune material due to natural or man-made processes along the coast are known as coastal erosion (Islam & Ryan, 2016). When new material is not deposited onto the beach to balance the movement of material away from it, a natural process known as coastal erosion takes place. Coastal landforms often experience quasi-periodic cycles of erosion and accretion over periods ranging from days to years. This is most obvious on sandy landforms like beaches, dunes, and occasionally closed and open lagoon entrances. However, human activity can also significantly impact how likely landforms are to erode. For instance, the building of seawalls, groynes, and breakwaters can alter the paths by which sediment moves along the coast, causing accretion in certain places and erosion in others. Unintended erosion can also be linked to remove sediments from the coastal system (e.g., through dredging or sand mining) or the restriction of sediment supply (e.g., through river management).

Coastal erosion in Sri Lanka has been identified as a long-term problem. Therefore, examining coastal sediment dynamics across the country is essential in preparing an appropriate coastal zone management plan. Accordingly, the conditions identified through the study are as follows: Past and recent Google Earth satellite imagery has been used to analyze erosion and accretion trends in the coastal zone around. Accordingly, in this research, remotely sensed images were analyzed. These remotely sensed images are very important to analyze geologic conditions temporally and spatially that cannot be measured by the eyes.

Using remote sensing technologies in conjunction with the Digital Shoreline Analysis System (DSAS) is a commonly employed approach to monitor shoreline alterations. The Digital Shoreline Analysis System (DSAS) is a statistical algorithm that utilizes multi-temporal satellite data, such as TM, ETM+, and OLI datasets, to quantify shoreline changes (Mansour et al., 2024). DSAS is often used as a predictive tool to assess short-term and long-term coastal changes. Coastal changes can occur over various time scales, from instantaneous events to long-term geological processes. The study of shoreline change represents a vital step in understanding the dynamism and evolution of the coastal areas, and stakeholders could do better to reduce the risk of coastal erosion and also minimize social, physical and economic loss.

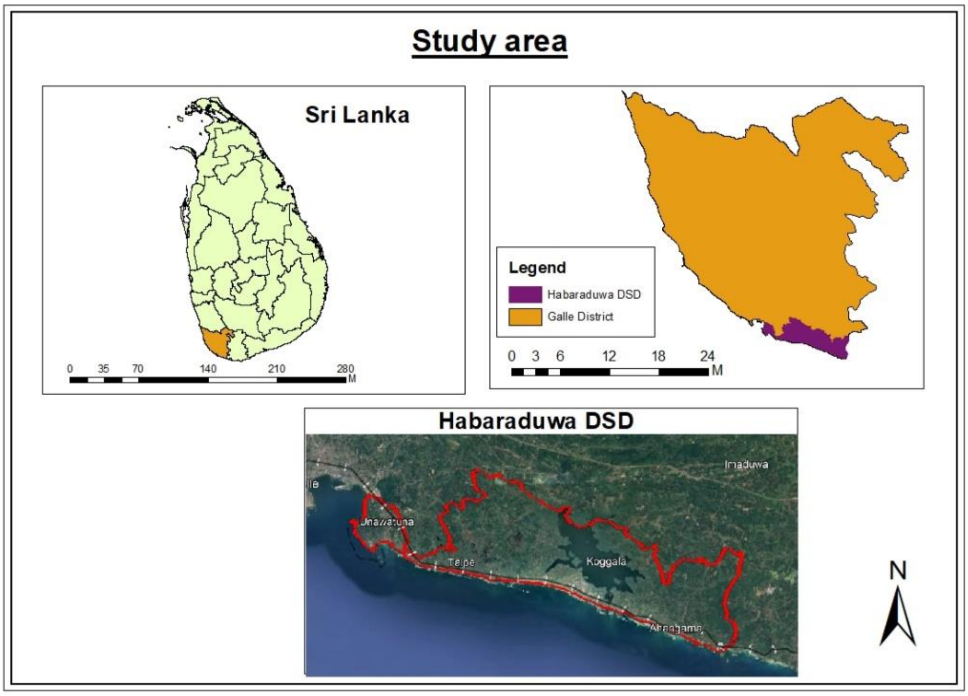
Land holds a central position in human existence and development. Land use refers to how humans utilize and modify the Earth's surface for different purposes. These activities include residential, commercial, industrial, agricultural, recreational, and conservation purposes. Essentially, it encompasses any human activity that involves altering or managing land for specific needs or functions. Understanding and managing land use changes are critical for sustainable development, as they involve balancing human needs and environmental conservation to ensure the long-term health and resilience of ecosystems and societies (Arunashantha, 2019).

This study aims to identify spatial and temporal shoreline changes (2006-2022) and land use changes in Habaraduwa DSD from 2008 to 2023. Through such studies, researchers can elucidate the coastline changes occurring on beaches and the associated problems arising from these alterations. Consequently, this knowledge facilitates developing and implementing effective solutions to mitigate these issues.

Methodology

Study area

The coastal area is the interface between the land and sea and has great ecological sensitivity and vulnerability. Habaraduwa DSD is known as the Administrative Secretariat Division, the eighth largest among Galle District's Divisional Secretariat Divisions and located near the coastal region. This division is adjacent to the coastal zone, about 3 miles inland. The location of the Divisional Secretariat in terms of north and east coordinates can be indicated as follows: North latitude is between 5˚-55' and 6˚-55', and east longitude is between 80˚-15' and 80˚-25'.



Source; Complied by Author,2024.
Figure 01; Study Area

This research is based on an inductive approach and primarily uses quantitative data. Thus, the Digital Shoreline Analysis System version 5.1 software was used to study the changes in the shoreline. One of the main benefits of using DSAS in coastal change analysis is its ability to compute the rate-of-change statistics for a time series of shoreline positions. The statistics allow the nature of shoreline dynamics and trends in change to be evaluated and addressed. Accordingly, the coastlines considered (years 2006, 2011, 2015, and 2022) were digitized through Google Earth Pro. After directing the divers to the ArcMap 10.7 software, it should merge all the coastlines using the merge tool. Shoreline data must be formatted with the appropriate attributes for use within DSAS. This study uses the Digital Shoreline Analysis System (DSAS) to calculate change rates. A shoreline change estimation is obtained using two statistical approaches: distance and rate. The three parameters, the Net Shoreline Movement (NSM), the Shoreline Change Envelope (SCE), and The End Point Rate (EPR), are mainly used to study the change in the coastline.

The land use of Habaraduwa DSD, an urban and coastal area, has undergone various changes. Thus, the temporal and spatial change of land use in the Habaraduwa DSD from 2008 to 2023 was studied. The analysis was done using data obtained from the Land Use Policy Department to study land use changes in the area. Fourteen land use classes were considered, which include other agriculture, barren lands, Built areas, Coconut, Cinnamon, Forest areas, Wetlands, Paddy, Rubber, Rocky areas, Scrub areas, Sand, Tea, and Water bodies. In the description of the land use classes considered in the study, area estimates were obtained for each polygon representing the relevant land use type, and land use maps were created for 2008, 2018 and 2023 to show the change in land use in Habaraduwa DSD between 2008 and 2023. Also, the land extents were calculated in square kilometers based on the land use types that changed in the 15 years from 2008 to 2023. The land extents were calculated as a percentage and analyzed to see how they changed temporally and spatially.

Table 01; Land use class description of reference criteria.

	LULC Class	Description of reference criteria
01	Other agriculture	Areas of other plantation crops besides the main plantation crops.
02	Bare lands	Areas of bare soil without significant vegetation, build-up and water regions
03	Built-up area	Areas of main towns, cities, build-ups, homestead and gardens
04	Coconut	Areas of coconut distribution
05	Cinnamon	Areas of cinnamon distribution
06	Forest Land	Areas of natural forest and patches of vegetation
07	Wetland	Areas of wetland distribution
08	Paddy	Areas of paddy distribution
09	Rubber	Areas of rubber distribution
10	Rocky area	Areas of rocky distribution
11	Scrub	Areas of scrub distribution
12	Sand area	Area of sand and beaches
13	Tea	Areas of tea distribution
14	Water bodies	Areas of natural water bodies and artificial waterways and channels

Source; Complied by Author using literature survey, 2024.

To fulfil the secondary objective of the study, how land use has changed over time was analyzed using ArcMap 10.7 software using land use data obtained from the Land Use Policy Planning Department. This way, the land amount related to each land use was calculated. After that, the percentage changes in land use were studied. Also, how land use may change in the future can be predicted through the following equation:

$$TC = \left[\frac{(E_2 - E_1)}{\Delta y} \times nx\right] + E_2$$

Source; (Jayarathne et al., 2023).

The research design can be described as follows;

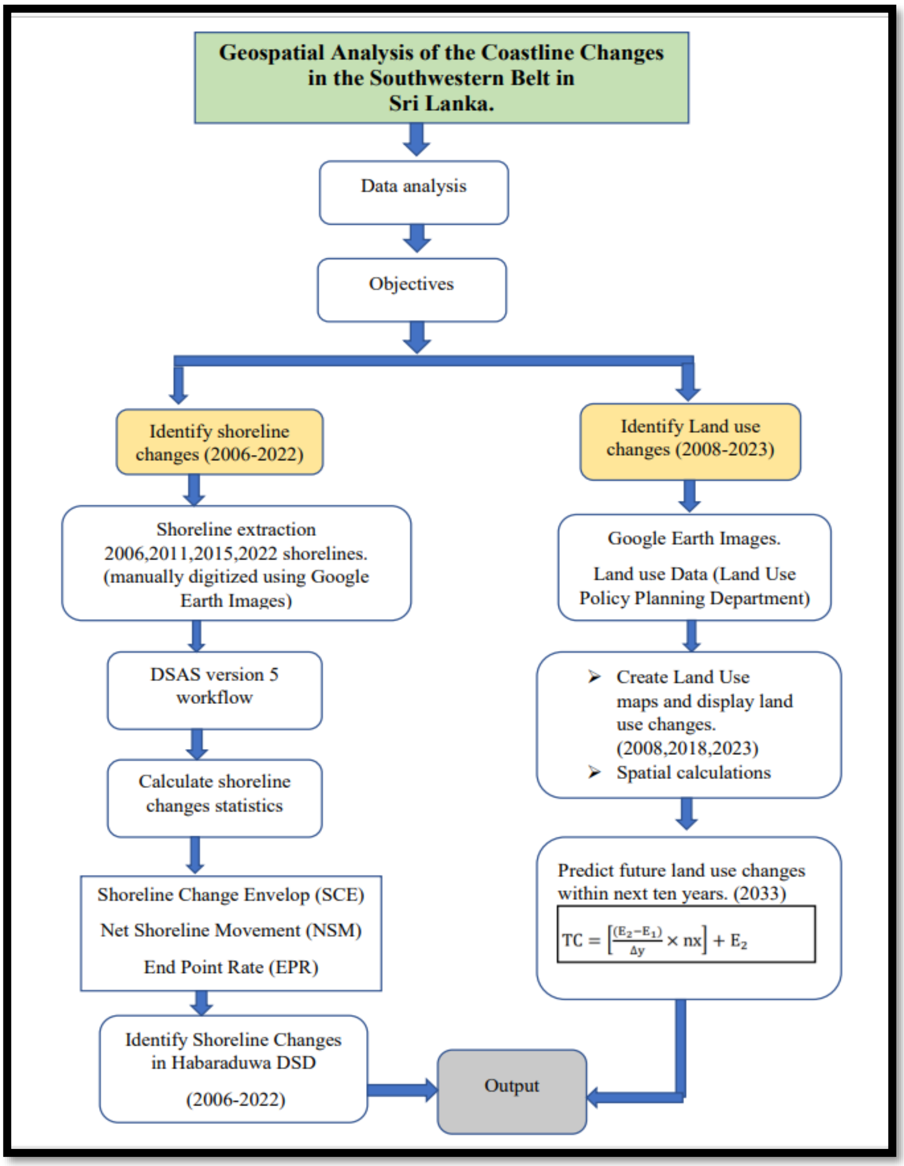


Figure 02; Research Design
Source; Complied by Author,2024

Literature Review

The coastal zone is the bridge between the ocean and the mainland, the junction of the two ecosystems, the focus of the economic development of coastal cities, and the gathering place of ports (Yong & Chen, 2021). And also, the coastal zone is a dynamic and diverse environment that plays a critical role in supporting life on Earth. Sustainable protection and management of coastal ecosystems is essential to ensure the well-being of human societies and the natural world. Due to the combined effects of climate change and human activities, the coastal zone ecosystems and natural environment are extremely fragile, showing that the region is highly dynamic, complex, and diverse (Han et al., 2022). The coastal zone is a dynamic and diverse area that plays a crucial role in both natural and human systems. It typically extends inland from the shoreline to include areas influenced by coastal processes and features, such as estuaries, lagoons, tidal flats, salt marshes, mangroves, rocky shores, and sandy beaches.

Remotely sensed images are commonly used in analyzing the spatial and temporal patterns of environmental variables over the past decades due to the dynamic changes occurring in coastal areas worldwide (Lillesand, 1994). The geographic information system (GIS) is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information. According to (Dueker,1979) the GIS is a special case of information systems where the database consists of observations on spatially distributed features, activities or events, that are definable in space as points, lines, or areas. The concept of the geographic information system emerged during the 1960s and 1970s as a new trend to produce maps in order to be used for resource assessment, land evaluation, planning and environmental monitoring.

The Southwestern Coastal Zone is defined as that stretch of the coast that extends from Galle to Colombo (Lighthouse). It is situated between the longitudes 79'.50 E and 80.1 5'E and the latitudes 6°.00'N to 6'.56'N. The total length of the Southwestern Coastal Zone covered by the field survey was 135 km. This area is depicted in 5 one-inch topographical map sheets and 26 aerial photographs (1:40,000). Almost the entire coastline faces the Southwest, thereby exposing itself to the full brunt of the southwest monsoon.

Sri Lanka's southwestern coastal belt is a picturesque stretch of coastline renowned for its stunning beaches, vibrant culture, and rich biodiversity. Extending from Colombo, the capital city, down to the historic city of Galle, this region offers an array of attractions that draw tourists from around the globe. From pristine beaches to quaint fishing villages, the southwestern coast of Sri Lanka encapsulates the essence of tropical paradise. The southwestern coastal belt is characterized by its sandy beaches, palm-fringed shores, and turquoise waters of the Indian Ocean. This region is part of the Southern Province of Sri Lanka and encompasses popular destinations such as Mount Lavinia, Bentota, Hikkaduwa, Unawatuna, and Mirissa. The coastline is dotted with numerous coves, bays, and estuaries, providing diverse landscapes for travelers to explore. The coastal erosion is one of the major chronic hazards prevailing in the country, mainly due to human-induced acceleration. Many erosion hotspots are on the western, southwestern and southern coasts. The Intensity of shoreline erosion is high in the Southwestern coastal sector, among others in Sri Lanka (Bakker, 2018; CCD, 1986). The intensity of shoreline erosion is particularly pronounced in the southwestern coastal sector.

The two terms "shoreline" and "coastline" are commonly defined as the physical interface of land and water (Dolan, Hayden, 1980). The Shoreline, which is the boundary between land and sea, keeps changing its position continuously due to dynamic environmental conditions. It is one of the most rapidly changing landforms on earth (Chorly et al., 1984). (Lam and Qiu,1992) consider that the shoreline represents the dynamic boundary between land and water, a continuous and often indented line that includes numerous small bays and prominent points, and the coastline refers to the outer, more stable and more general shape of the shore. The interface, border, or short strip that separates land from bodies of water, like lakes or the sea, is known as a shoreline. This region is dynamic in nature and has a linear feature that changes quickly. It is frequently influenced and regulated by a variety of coastal phenomena, including climate, wave dynamics, sediment characteristics, slope, and tidal fluctuations (Misra & Balaji, 2015). In contrast, the coastline is a broader term that refers to the boundary between the land and the sea, including the immediate shoreline and the land features and characteristics that extend inland from the shore. This includes coastal plains, estuaries, dunes, wetlands, and other features influenced by coastal processes. The coastline represents the entirety of the geographical interface between land and sea, encompassing both the immediate shoreline and the land features shaped by coastal processes.

Coastal zones are frequently the sites of dense growth because of the dynamic interactions between land and ocean. Changes in the shoreline caused by accretion and erosion are natural processes that happen across a variety of periods. The coastal erosion is one of the significant chronic hazards prevailing in the country. In Sri Lanka, the coastal region contributes a lot to the national economy while also providing a home for the large population. Due to the coastal erosion, critical infrastructure, human settlements, the livelihood of the rural population, and two significant sectors of tourism and fisheries are severely affected. Many erosion hotspots are in the western, southwestern and southern coasts, but few cases are even in the eastern, north-eastern and northern coasts. As a result, annually many public and private properties have been damaged or are under threat. Fishing, tourism and critical services have been disrupted.

Food and Agriculture Organization (FAO) defines land as “a delineable area of Earth’s terrestrial surface. Land holds a central position in human existence and development. Since their appearance on earth, humans have used land and its resources to meet their material, social, cultural, and spiritual needs. "Land use" describes how people utilize land. This broad category includes cities, industry, infrastructure, mining, and agriculture. Land use refers to changes in land use on the Earth’s surface caused by human activities (Han et al., 2022). Furthermore, the term "land use change" describes any modification to the way land is used, including adjustments to land cover and land management techniques. Numerous factors, including population density, economic status, technical advancements, industrial structure, and political actions, influence it. Land use is a complex and dynamic process that reflects the interplay between human societies and the environment. Future changes in land use in the coastal zone are no less affected by climate change. The main impact of climate change on the coastal zone will be adverse conditions due to sea level rise, with possible increases in the frequency and intensity of storms.

Results and discussion

Different techniques are available in the scientific literature to analyse shoreline changes. GIS and remote sensing are widely used techniques for change analysis. This study also used GIS and remote sensing for coastal zone change analysis. In addition, the DSAS was used as an effective tool to study shoreline changes in the study region from 2006 to 2022. In this study, the DSAS is used to calculate change rates. A shoreline change estimation is obtained using two statistical approaches: distance and rate. The three parameters, NSM, SCE, and EPR are mainly used to study the change in the coastline. SCE is the distance between the shoreline furthest from and closest to the baseline at each transaction. It represents the total change in shoreline movement for all shoreline positions. NSM reports the distance between each transect's earliest and most recent shoreline. It represents the total distance. EPR is calculated by determining the distance between the oldest and most recent shorelines in the data and dividing it by the years between them. This method provides the net rate of change over the long term.

Identify Spatial and Temporal Shoreline Changes.

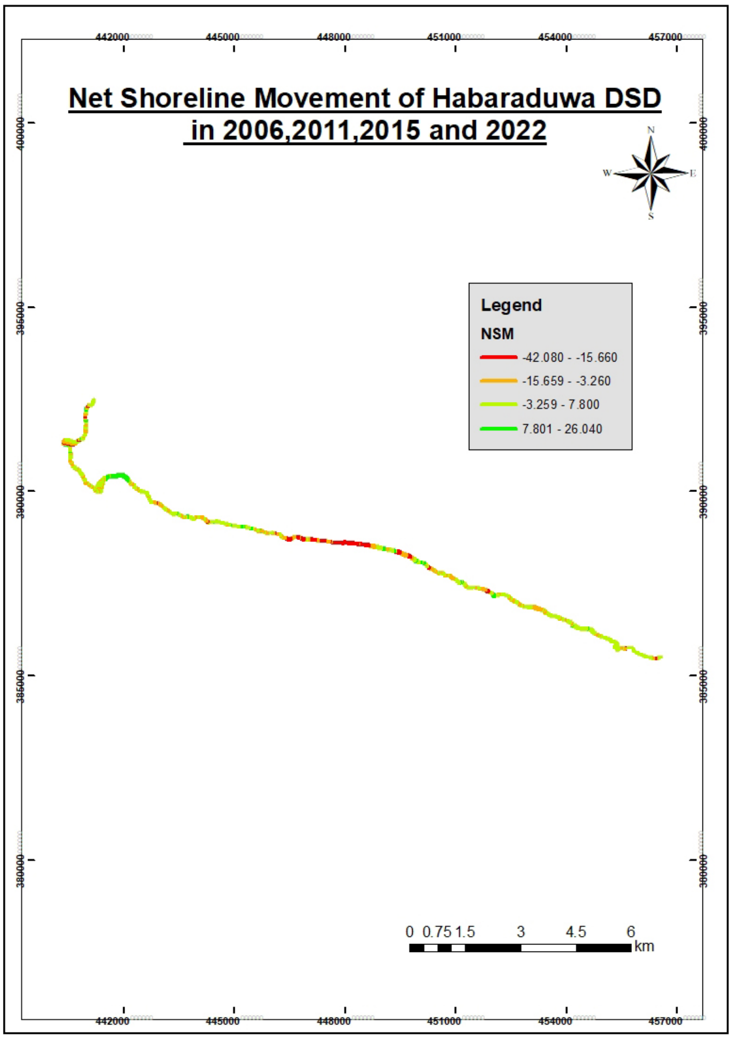
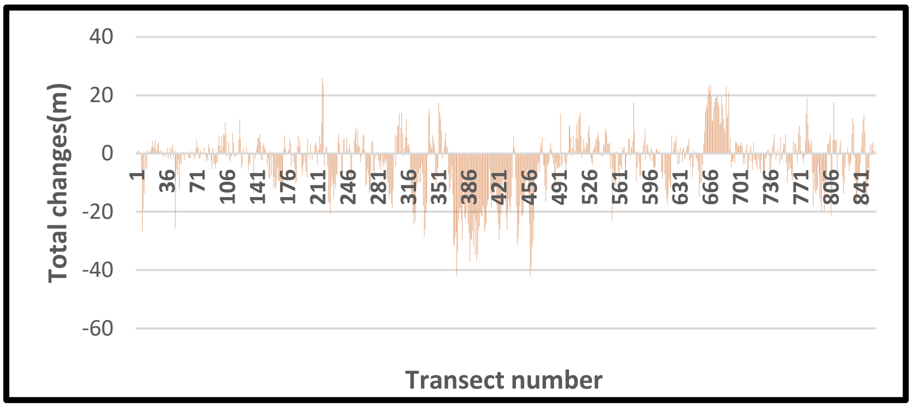


Figure 3; Net shoreline Movement of Habaraduwa DSD in 2006-2022
Source; Complied by Author,2024

The above map shows the change in the coastline of the Habaraduwa area from 2006 to 2022. This change is based on the NSM parameter. According to the NSM parameter, the highest negative value is -42 meters. This NSM value is measured in meters. Accordingly, the area with the highest NSM value is indicated in red on the map. Negative values represent the minimum distance between the old and recent Shorelines, indicating area of beach erosion. Conversely, positive values indicate accumulation, with the highest recorded value being 26.04 meters. Overall, the map shows moderate occurrences of both beach erosion and accretion.

The graph below shows how NSM values vary when studying shoreline changes over time.

Graph;1 Net Shoreline Movement (NSM) in Habaraduwa DSD 2006-2022.

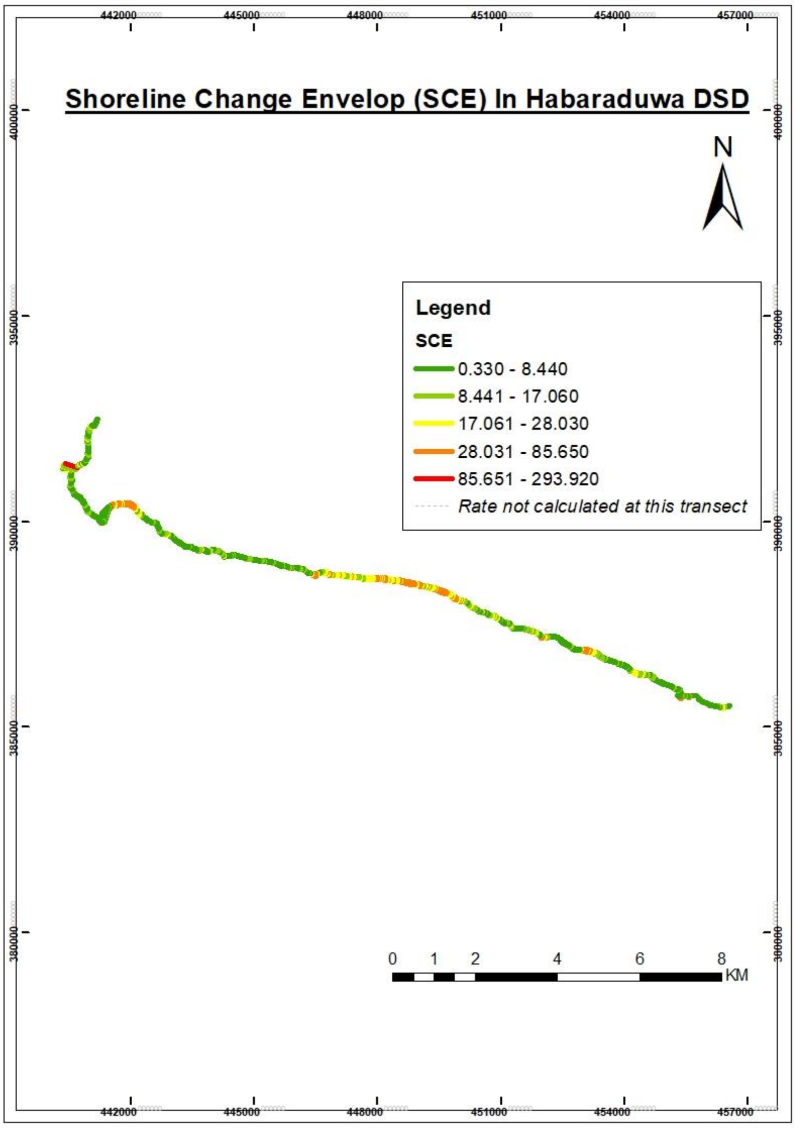


Source; Complied by Author,2024.

The NSM values can be calculated according to the positive and negative values in the graph above. Thus, the positive values show an accumulation whereas the negative values show erosion levels. It is very clear from the graph that coastal erosion has occurred at a small and significant level. Thus, the beaches have not remained stable from 2006 to 2022. Apparent changes can be seen in the coastal belts. These changes in the coastal belts have affected the morphology of the beaches.

Another important parameter for studying shoreline change is SCE. The SCE value represents the maximum distance among all the shorelines intersecting a given transect and reports this distance in meters, not a rate. The SCE measures the greatest distance between shoreline intersecting value represents the most incredible distance among all the shorelines intersecting a given transect. SCE measured the most significant distance between shorelines in 2006, 2011,2015 and 2022. The value represented the total change (accretion or erosion) in shoreline by meter (m) unit in a single transect.

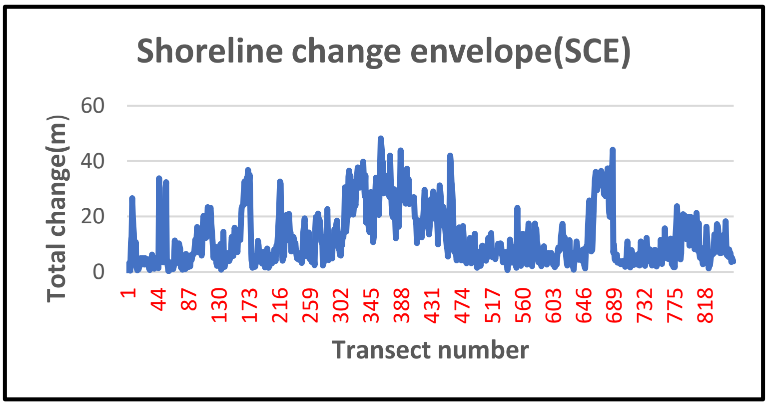
The map below shows how the SCE values have been applied to the shorelines of Habaraduwa in 2006, 2011, 2015 and 2022.



Source; Complied by Author using DSAS,2024
Figure 4; Shoreline Change Envelope of Habaraduwa DSD in 2006-2022.

According to the above map, the SCE values are all positive indicating the maximum distance among the given coastal strips. These values help whether erosion or accretion has occurred. To calculate the Shoreline Change Envelope (SCE) for the period from 2006 to2022, and shorelines from the years 2006, 2011, 2015, and 2022 were used. The SCE value represents the total change in shoreline position across all available shorelines. The map shows that the highest SCE value is 48.2 meters while the minimum value is 0.33 meters. Accordingly, the most significant maximum distance between all coastlines is 48.2 meters. An increase in this indicates erosion, while a decrease suggests beach accretion.

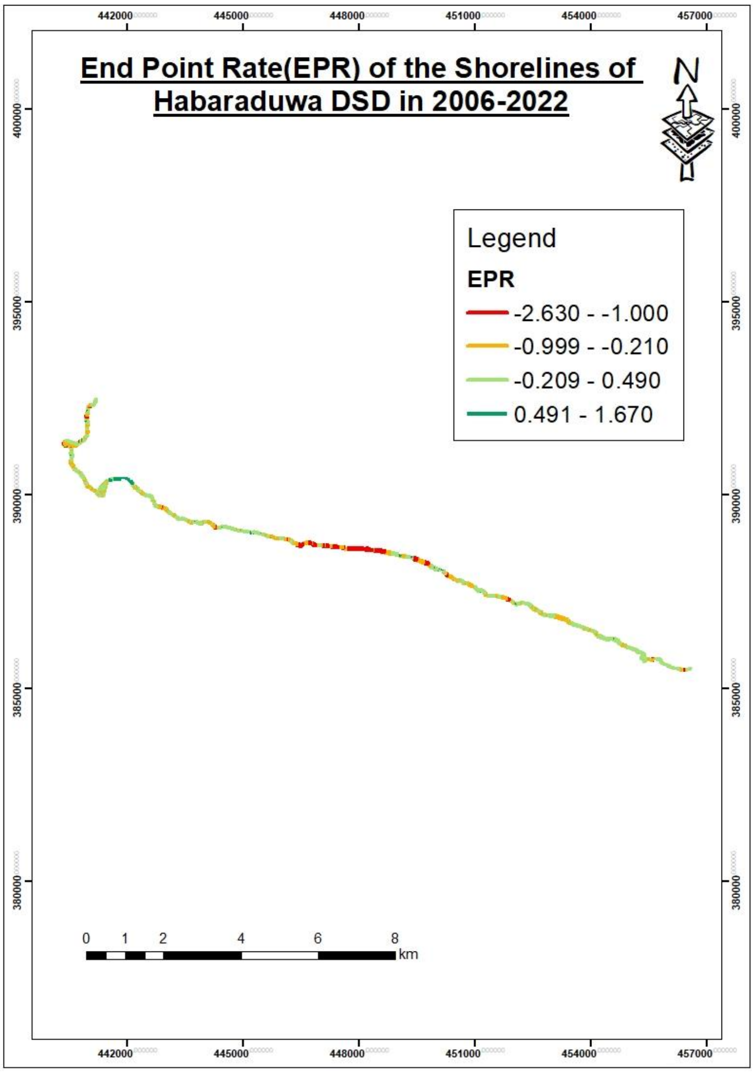
Graph 02; Shoreline Change Envelope in Habaraduwa DSD in 2006-2022.



Source; Complied by Author,2024.

The SCE value in Figure 1 represents the distance between the shoreline furthest from and closest to the baseline. Due to the extent of the study area and variations along the coastal areas, the shorelines defined as furthest from and closest to the baseline vary for each transect. The map shows a maximum distance of 991.57 meters, defining this as a maximum of accretion.

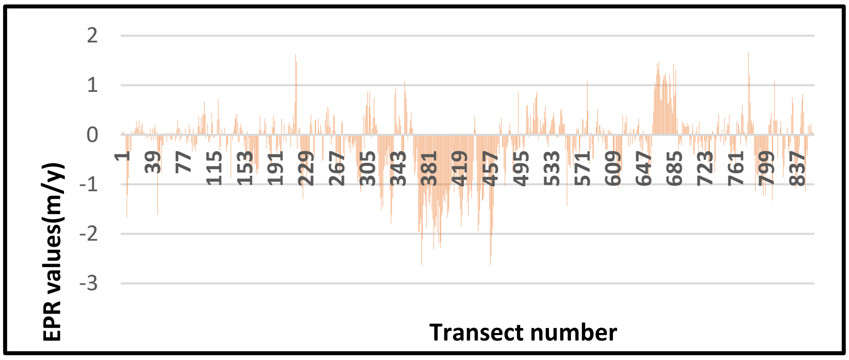
The EPR is another critical statistical method for identifying shoreline changes. The EPR is calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline. The significant advantages of the EPR are the ease of computation and the minimal requirement of only two shoreline dates. The disadvantage is that in cases where more data is available, the additional information is ignored. Changes in sign (in other words, accretion to erosion), magnitude, or cyclical trends may be missed (Himmelstoss et al., 2021).



Source; Complied by Author using DSAS,2024
Figure 5; End Point Rate (EPR) of the Shorelines in Habaraduwa DSD in 2006-2022.

The EPR model predicts future coastline positions using prior rate of change data. The EPR analysis represents the speed of accretion and erosion in meters per year. Figure 4 presents the maximum accretion rate reaching 1.67 meters / year, while erosion rates reach a maximum of – 2.63 meters / year.

Graph 3; End Point Rate of Habaraduwa DSD in 2006-2022.



Source; Complied by Author,2024

Table 02; Data collection of DSAS statistical methods.

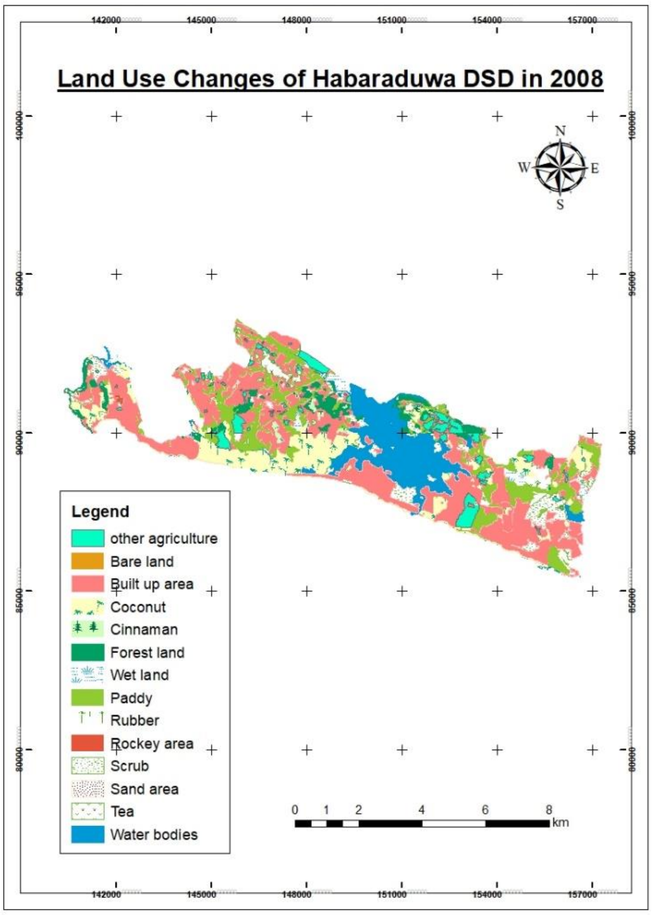
Subject	**SCE(m)**	**NSM(m)**	**EPR(m/y)**
Average	12.195	-3.0456	-0.189
Maximum	48.22	26.04	1.67
Minimum	0.33	-42.08	-2.63

Source; Complied by Author,2024

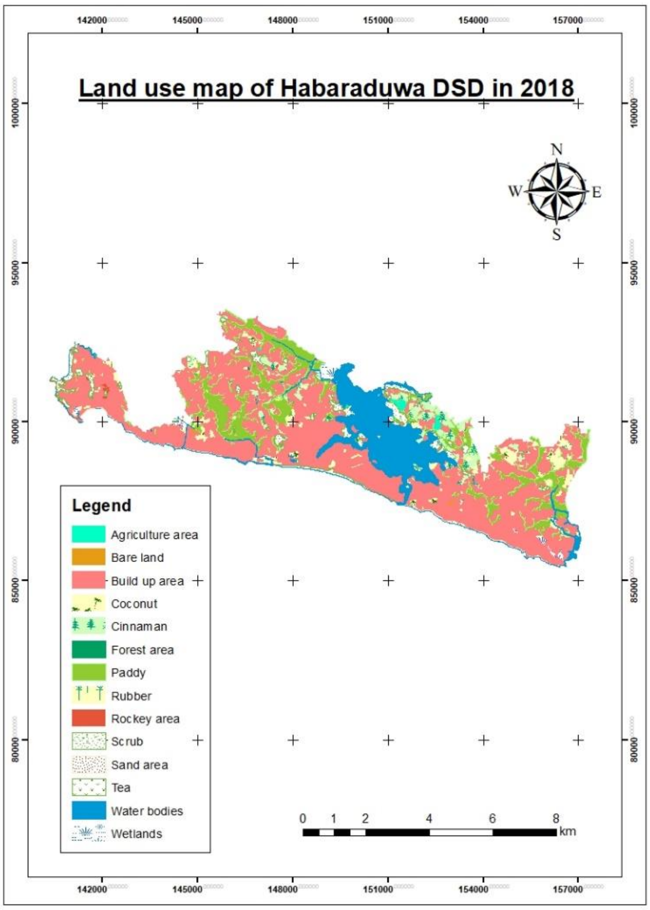
The above table summarizes the data obtained by analyzing the changes in coastlines using statistical parameters according to DSAS Version 5. Therefore, the coastal changes were identified using the statistical parameters of SCE, NSM, and EPR. Accordingly, the average, maximum, and minimum values of erosion can be identified and how accumulations have occurred, and the corresponding coastal areas can be determined.

Identify Land Use Changes (2008-2023)

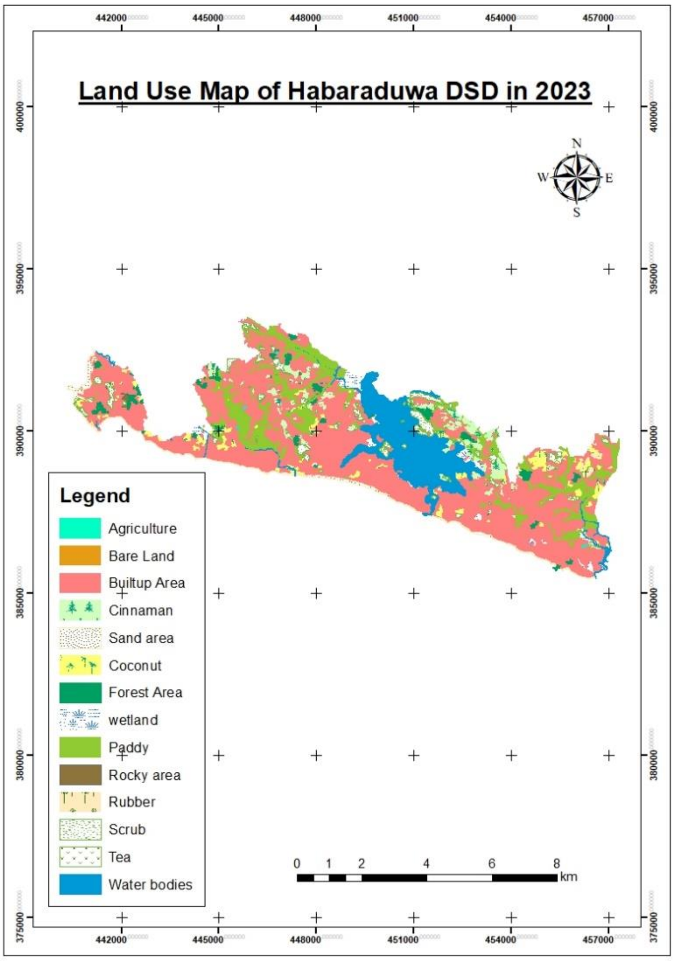
Mapping was carried out using ArcMap 10.7 software. Eleven LULC classes were considered, which include categories: agricultural areas, abandoned land, built-up areas, coconut plantations, cinnamon plantations, forest areas, wetland areas, rocky areas, grassy areas, sandy areas, and coastal areas.



Source; Complied by Author,2024
Figure 06; Land Use of Habaraduwa DSD in 2008



Source; Complied by Author,2024
Figure 07; Land Use of Habaraduwa DSD in 2018



Source; Complied by Author,2024
Figure 08; Land Use of Habaraduwa DSD in 2023

According to the spatial analysis, the predominant land use in the Habaraduwa region is attributed to built-up areas, which account for 36.49% of the total land. Paddy cultivation occupies approximately 7 square kilometers, constituting 14.43% of the overall area. Given the coastal location of Habaraduwa, coconut cultivation was prevalent in 2008, covering 6% of the total land area. Additionally, thorn grass and thorn forest cover an area of 3.14 square kilometers, representing 6.44% of the total. Forested areas, influenced by the urban characteristics of the region, are limited to a relatively small expanse of 2.66 square kilometers. According to the spatial analysis, the predominant land use in the Habaraduwa region is attributed to built-up areas, which account for 36.49% of the total land. Paddy cultivation occupies approximately 7 square kilometers, constituting 14.43% of the overall area.

The percentage of land area devoted to main plantation crops is relatively law, at only 5.45%. Other agricultural lands, including other crops, cover approximately 5% of the area. Wetlands have expanded by 2%. While rubber, a main plantation crop, occupies minimal areas of 1.4% and 1.1%, respectively. Water sources are also a crucial factor covering an area of 6.7 square kilometers, which is 12.71% of the total area. Among these, Koggala Lake is a significant water source.

Land use changes in the Habaraduwa Divisional Secretariat Division over a ten-year period from 2008 to 2018 reveal that socio-economic factors have has a greater impact than natural causes. Factors such as population growth, the tourism industry and urbanization have driven these changes. As indicated in Table 3, the built-up area in the Habaraduwa Divisional Secretariat increased to 25.65 square kilometers by 2018, reflecting a growth of 52.49% compared to 2008. In contrast, of the area dedicated to agricultural crop cultivation has decreased. Paddy cultivation which covered 14% of the total land area in 2008 decline to 12% by 2018.Coconut cultivation which was previously 3.86 square kilometers or 7.9% of the total land area in 2008, has also seen a reduction. Additionally, forest cover in the region has significantly declined from 2.6 square kilometers in 2008 to just 1 square kilometers by 2018.This analysis confirms a significant decline in agricultural crop areas and a marked expansion of built-up regions over the decade.

After the year 2018, about five years later, by the year 2023, the land use of Habaraduwa Divisional Secretariat had undergone further changes. This Habaraduwa area is located next to Galle City in Galle District, the main administrative district of Southern Province. This area will have undergone many changes in land use by the year 2023 due to various factors such as urbanization, industrialization, population growth, etc. As shown in the Figure 08, the built-up area has further developed. It covers an area of 29.25 square kilometers. In this area, in the year 2008, several places with rubber plantations have become built-up areas. Due to the strong expansion of the tourism industry in this area, agricultural lands have become built-up areas. Also, as shown in the 2023 land use map, all the lands adjacent to the coast on that map have become built-up areas. It can be further concluded that the number of built-up areas in the area has increased due to socio-economic activities. And by 2023, paddy fields have spread in an area of 5.18 square kilometers. It has a percentage value of 10.6%. Every land use in this area has undergone changes in time and space. Compared to the year 2018, land use in 2023 has clearly changed.

Table 03; Land use of Habaraduwa DSD in 2008,2018 and 2023

	2008		2018		2023	
Land use	**Land extent (sqkm)**	**Percentage**	**Land extent (sqkm)**	**Percentage**	**Land extent (sqkm)**	**Percentage**
Built up area	17.834	36.49%	25.65	52.49%	29.25	59.86%
Paddy area	7.056	14.43%	6.27	12.83%	5.18	10.6%
Water bodies	6.702	13.71%	6.27	12.83%	6.2	12.68%
Coconut	6.005	12.28%	3.86	7.9%	1.89	3.86%
Scrub	3.147	6.44%	2.08	4.25%	1.75	3.58%
Forest land	2.665	5.45%	1.1	2.25%	0.95	1.94%
Other Agriculture	2.444	5%	0.2	0.4%	0.51	1.04%
wetland	1.023	2.09%	0.47	0.96%	0.37	0.75%
Rubber	0.719	1.47%	0.28	0.57%	0.29	0.59%
Tea	0.553	1.13%	0.17	0.34%	0.13	0.26%
Cinnamon	0.275	0.56%	2.13	4.35%	1.48	3.02%
Sand area	0.218	0.44%	0.22	0.45%	0.77	1.57%
Bare land	0.114	0.23%	0.05	0.1%	0.01	0.02%
Rocky area	0.11	0.22%	0.11	0.22%	0.08	0.16%
TOTAL	**48.86**	**100%**	**48.86**	**100%**	**48.86**	**100%**

Source; Complied by Author,2024

In this way, the land use pattern has changed temporally and spatially from the year 2008 to the year 2023 over time, as can be seen from the above table.

Table 4; Change of the land extent (sqkm) of Habaraduwa DSD in 2008,2018 and 2023.

Land use	**Change of the land extent(sqkm)±**		**Change of the land extent(sqkm)±**	
	2008-2018 time period	**Percentage**	**2018-2023 time period**	**Percentage**
Built up area	17.834-25.65 = 7.816	40.39%	25.65-29.25= 3.6	40.26%
Paddy area	7.056-6.27= 0.786	4.06%	6.27-5.18 = 1.09	12.19%
Water bodies	6.702-6.27= 0.432	2.23%	6.27-6.2= 0.07	0.78%
Coconut	6.005-3.86= 2.145	11.08%	3.86-1.89= 1.97	22.03%
Scrub	3.147-2.08= 1.067	5.51%	2.08- 1.75=0.33	3.69%
Forest land	2.665-1.1= 1.565	8.08%	1.1- 0.95 =0.15	1.67%
Other Agriculture	2.444-0.2= 2.244	11.59%	0.2- 0.51=0.31	3.46%
wetland	1.023-0.47= 0.553	2.85%	0.47- 0.37= 0.1	1.11%
Rubber	0.719-0.28= 0.439	2.26%	0.28-0.29=0.01	0.11%
Tea	0.553-0.17= 0.383	1.97%	0.17-0.13= 0.04	0.44%
Cinnamon	0.275-2.13= 1.855	9.58%	2.13- 1.48= 0.65	7.27%
Sand area	0.218-0.22= 0.002	0.01%	0.22- 0.77= 0.55	6.15%
Bare land	0.114-0.05=0.064	0.33%	0.05- 0.01= 0.04	0.44%
Rocky area	0.11-0.11=0	0	0.11- 0.08=0.03	0.33%
	19.351		**8.94**	

Source; Complied by Author,2024.

As shown from the above maps and tables, it can be observed that the built-up area in the Habaraduwa area has increased over time compared to the year 2008. Also, there has been a decrease in the agricultural land area. According to table number 4, the years from 2008 to

2018 built-up area has increased by 40.39% in ten years. Also, compared to the year 2008, paddy cultivation areas have decreased by 0.786% in 10 years by the year 2018, and it can be calculated as 4.06% as a percentage. Thus, it is clear that the paddy cultivation areas have decreased. Also, since 2008 and 2018, the forest areas have decreased greatly.

Compared to 2008, the percentage of decreased forests in 2018 is 5.51%. Also, rubber cultivation has changed by 2.26% in 10 years. Also, other agricultural land has changed significantly. The change is 2.244 square kilometers, and it is 11.59% as a percentage. Also, the cultivation of cinnamon in this area had spread to some extent and had decreased by 9.58% by 2018. Habaraduwa area is especially bordered by an urban area and a coastal area, so agricultural land has been spread to a minimum extent, and it will further decrease with time. Especially the forest cover has decreased by 8.08% in 10 years, which is problematic, as pointed out.

Also, in further explanation, according to Table No. 4, the area built has increased by 40.26% in 5 years from 2018 to 2023. Further, it can be indicated that land use has changed based on socio-economic reasons. Also, by the year 2023, a significant amount of paddy cultivation land that existed in 2018 will have been lost. The area under paddy cultivation, which was recorded at 6.27 square kilometers in 2018, is projected to decrease to 0.07 square kilometers by 2023. This represents a reduction to 12.19% of its original extent. Due to this, the number of built-up areas has increased for socio-economic reasons. Coconut cultivation had expanded to some extent, but by 2023, it had been reduced to 1.09 square kilometers in five years. As a percentage, land use has changed by 22.03%. Also, the cultivation of cinnamon in the area has decreased by 0.65 square kilometers. But there will be no significant reduction in water bodies by 2023. Water bodies have decreased by 0.07 square kilometers. It is clear that there has not been much reduction in the number of water bodies in the area from 2008 to 2023.

Future land use predictions are statistically analyzed using trend analysis, field observations, and verification. Transitional land use changes were calculated using statistical techniques according to the following equation:

$$\boxed{\mathrm{TC} = \left[\frac{(\mathrm{E}_2 - \mathrm{E}_1)}{\Delta \mathrm{y}} \times \mathrm{nx}\right] + \mathrm{E}_2}$$

TC = Temporal Change

E_1 – Values of the base year

E_2 – Values of the Considering year

n x – Period of prediction

Δy – Difference between the E_1 and E_2 (year gap)

According to the above equation, the land use of Habaraduwa Divisional Secretariat can be predicted for the next ten years.

Table 5; Future land use predictions of Habaraduwa DSD.

Land use	**Land extent (sqkm) 2008(E_1)**	**Land extent (sqkm) 2023 (E_2)**	**Land extent (sqkm) 2033 (L_1)**
Built up area	17.834	29.25	36.86
Paddy area	7.056	5.18	3.94
Water bodies	6.702	6.2	5.90
Coconut	6.005	1.89	-0.85
Scrub	3.147	1.75	0.82
Forest land	2.665	0.95	-1.14
Other Agriculture	2.444	0.51	-0.77
wetland	1.023	0.37	-0.06
Rubber	0.719	0.29	0.01
Tea	0.553	0.13	-0.15
Cinnamon	0.275	1.48	2.28
Sand area	0.218	0.77	1.14
Bare land	0.114	0.01	-0.06
Rocky area	0.11	0.08	0.06
TOTAL	48.86	48.86	48.8

Source; Complied by Author,2024

As shown in the above table, it is very important to predict how the land use may change in the future when looking at how the land use of the Habaraduwa area changed between 2008 and 2023. Thus, these predictions are used to identify the patterns and trends of land use change. As calculated in the table above, each land use type could change by 2033 over the next 10 years. Thus, predictions of land use for the next ten years can be provided.

Thus, it can be predicted that from the year 2023 to the year 2033, the built-up area will further increase to 36.86 square kilometers. Accordingly, it has increased to 7.61 square kilometers in 10 years. Also, it is estimated that the spread of paddy fields will further decrease. By 2033, paddy fields will cover an area of 3.94 square kilometers. Water sources will decrease to 5.90 square kilometers in 2033 compared to 2023. Thus, water sources have decreased by 0.3 square kilometers.

Thus, according to table number 5 above, the land use of Habaraduwa DSD will be predicted in the year 2033 based on the land use data of 2023. Accordingly, the coconut cultivation area in the year 2023 is 1.89 square kilometers, and after calculating it according to the above equation, the coconut cultivation land is 0.85 square kilometers in the year 2033. Accordingly, it is clear that the coconut cultivation areas are completely depleting. As per the data given to the equation, negative numbers are obtained because the land cannot show anything with a negative value; the negative values represent the depletion of the land use. In this way, according to the pattern of land use, forest land, wetlands, agricultural land, etc. will take a negative value by the year 2033, and it is clear that those land uses may depreciate. Thus, due to the increase in the amount of built-up area and urbanization in the area, the depletion of forest cover, agricultural land, and wetlands is a very serious problem. Therefore, these problems must be identified in advance and dealt with appropriately. Protection of wetlands, etc., should be taken.

Thus, after studying how the land use of Habaraduwa DSD has changed temporally and spatially from 2008 to 2023, it can be predicted that how the land use of Habaraduwa DSD may change in the next 10 years. Thus, it is essential to predict future land use. Based on the results of such forecasting, problems and challenges can be identified in advance, and necessary plans can be implemented to reduce those problems. Especially the coastal ecosystem, which is a very dynamic and sensitive ecosystem, can be managed sustainably.

Conclusion

Shoreline change in Habaraduwa DSD was studied using the statistical parameters NSM, SCE, and EPR, where the average value of the highest NSM is -3.045m and the highest and lowest values are 26.04m and -42.08 m, respectively. A positive value of NSM means accumulation on the beach. It is clear from the negative values that the coast has been eroded. Accordingly, the highest value of erosion has been revealed to be -42.08 meters. In this way, negative values are recorded at various places on the coast. Among them, the highest erosion is in Koggala, Ahangama, Habaraduwa, and Talpe, which are associated with beaches. Also, the average value of SCE is 12.19 meters, and the highest and lowest values are 48.22 meters and 0.33 meters, respectively. If the SCE value has the highest value, it can be called an eroded beach. Thus, the beaches with the highest SCE value are Unawatuna, Koggala, Ahangama, Habaraduwa, and Talpe. Also, the average value of EPR is -0.18, and the highest and lowest values are 1.67 and -2.63, respectively. The EPR analysis represents the speed of accretion and erosion in meters per year. Thus, the Koggala, Ahangama, and Habaraduwa coastlines were identified as having the highest erosion rate. In this way, it was found that the coastline of the Habaraduwa area changes over time and that there is a coastline that often changes seasonally.

Land use change in Habaraduwa DSD was analyzed from 2008 to 2023. The unique fact discovered is that land use has changed significantly over 15 years. Accordingly, an increase in the built-up area can be identified. It has changed by 40.39% in 2008–2018 and by 40.26% in 2018–2023. Predictions can be made about how the land use of Habaraduwa DSD may change in the future. Accordingly, in the analysis done using an equation, it was clear that the main change in land use in another ten years is the increased built-up land. By 2023, built-up land can increase up to 36.86 square kilometers. Other land uses can be predicted to decrease further.

Recommendation

It has been confirmed that the coastal areas of Unawatuna, Koggala, Ahangama, Habaraduwa Beach, and Talpe Beach, which fall under the jurisdiction of the Habaraduwa Divisional Secretariat, experienced significant erosion between the years 2006 and 2022.The research findings confirmed that the coastline in the Habaraduwa region undergoes temporal and spatial variations, indicating that its morphology is subject to seasonal changes.

Coastal morphological changes resulting from climate change represent a significant environmental issue. Therefore, it is essential to consider the findings of related research when addressing such environmental challenges, as well as when formulating legislation and making policy decisions. The alteration of coastlines and the consequent inundation of low-lying coastal areas represent significant environmental challenges. Accordingly, it is crucial to consider these research findings when addressing and mitigating such environmental issues.

The land use patterns within the Habaraduwa Divisional Secretariat have experienced substantial transformations between the years 2008 and 2023.From 2008 to 2023, land use changes demonstrated a significant increase in built-up areas, while agricultural crop lands experienced a substantial decline.

Based on the forecasts presented in the research, it is anticipated that land use within the Habaraduwa Divisional Secretariat will undergo substantial changes over the next decade. According to those predictions, by 2033, built-up areas will continue to grow rapidly and agricultural crops will continue to decrease. By the year 2033, it is projected that coconut cultivation, forest cover, wetlands, and the cultivation of rubber and tea may be entirely eradicated from this region. An analytical examination of land use within the Habaraduwa Divisional Secretariat from 2008 to 2023 suggest that if current trends continue, the region is likely to encounter a range of environmental, economic, and social challenges in the future.

Several regions, such as Unawatuna Beach within the Habaraduwa Divisional Secretariat, are of significant importance to eco-tourism. However, rapid changes in land use within these areas present challenges to the sustainability of eco-tourism and the broader tourism industry. Consequently, it is imperative that special consideration be given to the Habaraduwa Divisional Secretariat when developing land use plans, ensuring that eco-tourism is prioritized and potential negative impacts on the industry are mitigated.

With the growing reliance on modern technologies, such as geospatial tools, in the study of environmental changes, it has become increasingly important to ensure that decisions made are accurate and appropriate.

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