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Causes and Long-Term Challenges of Coastal Erosion (2004–2024): A Study in the Hikkaduwa Divisional Secretariat, Galle District

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ABSTRACT : Coastal zones are of exceptional importance in Sri Lanka due to the island with a broad coastline. However, both natural dynamics and increasing human interventions have accelerated changes along the coastline, resulting in serious environmental, social, and economic impacts. This study investigates the causes of coastal erosion and the long-term challenges associated with it, with especially emphasis on the Hikkaduwa Divisional Secretariat Division in the Galle District. The data required for DSAS, NDVI, and NDBI analyses were obtained through field-based questionnaire surveys, interviews, and USGS satellite imagery from 2004, 2005, 2014, and 2024. The results indicate a significant transformation in land-use and land-cover patterns since 2004, marked by a decline in vegetation cover and a substantial increase in built-up areas within the study area. This rapid built-up expansion has intensified pressure on demand for coastal resources and infrastructure, thereby aggravating erosion challenges. The study provides important insights into the current status of coastal erosion in Hikkaduwa and highlights its long-term challenges for sustainable regional development and the enhancement of community-based tourism initiatives in Hikkaduwa, Sri Lanka.

Keywords - Coastal Erosion, Hikkaduwa Divisional Secretariat, Land Use Changes, NDBI, NDVI

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1. INTRODUCTION

Sri Lanka, located in the northern Indian Ocean, is an island nation known for its varied and vibrant coastal landscape. Positioned between latitudes 5° 54′N and 9° 52′N and longitudes 79° 39′E to 81° 53′E, the country boasts a coastline of about 1,620 kilometers, including its bays and inlets but not its lagoons (Coastal Zone and Coastal Resource Management Plan [CZ&CRMP], 2024). The coastal region of Sri Lanka constitutes the lowest of the three peneplains that shape the island's geomorphology, primarily consisting of flat coastal plains with an average elevation of less than 30 meters (Coastal Zone Management Plan, 2018). Around the word, coastal zones home to nearly 45 percentage of the global population (United Nations Environment Program Report, 2022), and Sri Lanka is no exception, with one-third of its total population residing along its coastal belt. Population growth in these areas continues to rise, and coastal population density is expected to reach 134 persons per square kilometer by 2050 (Pussella & Gunarathna, 2022). This increasing population pressure has exacerbated the vulnerability of Sri Lankan coastal areas, contributing to significant environmental challenges, most notably coastal erosion.

Coastal erosion, a naturally occurring phenomenon, involves the gradual loss of coastline due to dynamic interactions between wind, water, and wave action. Coastal erosion, occurring since it is part of the geological processes, has worsened with human activities, thus threatening valuable land, ecosystems, and communities. Most of the erosional drivers, which are responsible for coastal erosion, are natural forces like wave action, tidal movements, and storm surges. The rate and severity of erosion are influenced by various factors, including wind strength, storm frequency, and the geological composition of the coastline. While rocky shorelines exhibit greater resistance to erosion, sandy beaches are particularly susceptible to rapid degradation.

Anthropogenic activities have further accelerated coastal erosion. The construction of coastal defense structures, such as seawalls, jetties, and piers, have altered the natural water currents and sediment transport, which would often lead to induced erosion in adjacent areas, Overdevelopment along coastlines, particularly through infrastructure expansion and tourism-related projects, has disrupted natural sedimentation processes. The impacts of climate change, such as rising sea levels and the increasing frequency of extreme weather events, have aggravated coastal erosion, especially in low-lying areas. The consequences of coastal erosion on the economy are severe. The loss of coastal land results in increased vulnerability to storm surges and flooding events, diminished economic opportunities for communities reliant on tourism and fisheries, and the destruction of wildlife habitat. Economic instability results from the severe erosion that damages vital infrastructure, such as buildings, ports, and roadways. As a result, many coastal communities are increasingly susceptible to displacement, resource scarcity, and long-term socio-economic instability, underscoring the urgent need for integrated coastal zone management and sustainable development practices.

Masselink and Russell (2013) conducted a comprehensive study on the impacts of climate change on coastal erosion, focusing on the coastlines of the UK and Ireland. Their findings indicate that a substantial portion of these coastlines is currently experiencing erosion, with approximately 17 percentage of the coastline of UK and 20 percentage of the coastline of Ireland being affected. In England and Wales alone, 28 percentage of the 3,700 km coastline is eroding at rates exceeding 10 cm per year. Based on this study, sea level history of the area, resistance of the geological features, relative sea level change, long-shore sediment transportation, waves, tides and storm changes and human impacts were affected due to coastal erosion in the study area. Moreover, the long-term response of the coastline to climate-induced pressures especially sea level rise was found to be strongly shaped by coastal management strategies. These strategies, which include hard engineering structures, beach nourishment programs, and managed realignment approaches, play a critical role in determining how the coast adapts to ongoing environmental changes.

Yantikoua et al. (2023) studied an Assessment of the vulnerability of the southwestern coast of Benin to the risk of coastal erosion and flooding. Researchers applied a participatory approach based on a mixed research method including quantitative surveys and qualitative surveys to identify the impacts of coastal hazards. This research suggests that coastal erosion has accelerated the loss of ecosystems and habitats, including mangroves and coastal reefs, which has resulted in the forced relocation of local populations. Coastal erosion has caused 06 districts to lose about 8.6 hectares of land overall. In addition to temporarily interrupting economic activities, coastal erosion has permanently reduced the land surface area and increased the food insecurity among households. Surveys indicated that sea level rise and coastal currents were mainly caused by the coastal erosion, and other causes were mentioned but accounted for a small proportion. The riparian populations use a variety of palliative strategies in response to the nearly constant coastal hazards.

Saengsupavanich et al. (2023) had done the study about the current challenges in coastal erosion management across Southern Asian regions, focusing specifically on Thailand, Malaysia, and Sri Lanka. From this study, researchers aimed to analyze the current status of coastal management in Thailand, Malaysia and Sri Lanka and to synthesize a common coastal management framework for those particular countries. According to their findings, coastal erosion in these nations is driven by several key factors, including strong monsoonal wave activity, disruptions to alongshore sediment transport caused by man-made engineering structures, the destruction of mangrove ecosystems, and a range of other human-induced activities. Based on the researchers, main causes of coastal erosion were monsoon waves, disruption of alongshore sediment transportation due to man-made engineering structures, mangrove destruction and other anthropogenic activities. After the investigations, researchers identified some key challenges related to coastal erosion; rapid urbanization and the construction of infrastructure, rising sea level because of climate change, inadequate coastal zone planning and management framework, deficit of sediment supply compared to erosion rates.

Sri Lanka has long recognized coastal erosion as a critical environmental and socio-economic challenge. Historically, erosion was predominantly observed along the southern coastline and was initially perceived as a natural phenomenon. However, both natural forces and human interventions have contributed to the intensification of this process. In response to these challenges, substantial financial investments have been made to mitigate erosion. Between 1985 and 1999, approximately Sri Lanka rupees (LKR) 1,520 million were allocated for coastal erosion management. Subsequently, between 2001 and 2007, LKR 3 billion expended under the Asian Development Bank (ADB)-funded Coastal Resource Management Project. Additional funding of USD 1.4 million was allocated for coastal rehabilitation under the Tsunami Affected Area Rehabilitation Program (TAARP). More recently, from 2014 to 2022, LKR 6.3 billion was invested in coastal conservation initiatives (CZ&CRMP, 2024).

In 1994, the Coastal Resource Management project of the University of Rhode Island was published as 'The Coastal Environmental Profile of Hikkaduwa, Sri Lanka. It provided an in-depth analysis on geographical and physical features, natural resources, population and infrastructure, economic dynamics, institutional framework and opportunities of Hikkaduwa. This project is based on both primary and secondary data collection methods. As well as it referred Hikkaduwaas the site of Special Area Management (SAM). The project was aimed to improve management of the coastal resources of Hikkaduwa and stimulate a long-term process which can be replicated in other coastal areas of Sri Lanka. According to this report, Hikkaduwa severely suffered from issues resulting from unplanned and uncoordinated tourism development. Also, it identified some major issues; degradation of the coral reefs, declining coastal water quality, sedimentation of the coral reef, coastal erosion, increasing traffic congestion and conflict between different groups. Shanmugaratnam (2005) studied Challenges of Post Disaster Development of coastal areas in Sri Lanka. A post disaster, there were new opportunities for human development, investment and expansion, sustainable resource utilization, human capital formation, employment creation, and reconciliation. Researcher identified some linkages between war and coastal areas affected by Tsunami in Sri Lanka.

Among the most erosion-prone areas in Sri Lanka, the Galle district stands out as particularly vulnerable. Within this region, Hikkaduwa and Habaraduwa have been identified as high-risk locations for severe coastal erosion (CZ&CRMP, 2024). The table below highlights the key erosion-prone sites, and the specific challenges faced in each area.

Table 1: Emergency Coastal Erosion reported Locations in Galle District 2014-2022

Erosion Location/ Coastal Stretch	Status of Coast	Notified Problems
Ahangama	Ahangama Kanda – Laterite Cliff, Ahangama Town area – Narrow Beach	Moderate Cliff Erosion Severe Coastal Erosion
Unawatuna, Habaraduwa, Koggala	Seasonally change Sandy Beach, Fishery Dominant Coast	Severe Erosion
Dalawella	Mostly Laterite Cliff be existent, Previously Protected Stretch	Severe Erosion overtopping recorded
Dewata	Narrow Beach in off monsoon, Highly congested with coastal and building structures at the edge of coast line	Moderate Erosion
Gintota, Boossa, Rathgama	Majority of coast previously protected with structures coastline is congested with buildings Narrow Beach	Moderate Erosion overtopping reported

Hikkaduwa, Dodanduwa	Sandy Beach seasonal Erosion reported, Highly congested with coastal and building structures at the edge of coastline	Severe Seasonal Erosion
Kahawa	Sandy Beach, Adjacent to main road	Over topping recorded

One of the most devastating events in Sri Lanka's coastal history was the 2004 Indian Ocean tsunami, which significantly exacerbated coastal erosion and caused extensive damage to both natural and man-made coastal structures. Depending on the location, the tsunami waves ranged in height from one to fifteen meters and reached the Sri Lankan coastline approximately two hours after the earthquake off the coast of Indonesia. In Koddiyar, located in the Ampara District, the highest recorded wave height was 15 meters, with seawater inundation extending up to 3.5 kilometers inland in some areas (Survey of the December 26th Indian Ocean Tsunami in Sri Lanka, James Goff, International Tsunami Survey Team, as cited in CZ&CRMP, 2024).

Wijerathne et al. (2023) studied on An Evaluation of the Land-use Changes and the Associated Environmental Impact of coastal tourist destinations: A comparative study of the Hikkaduwa and Bentota sites. The objective of their research was to assess how the rapid growth of the tourism industry has influenced land-use patterns in these areas and to examine the resulting environmental impacts. The study focused on Hikkaduwa and Bentota, two of the most prominent tourist destinations along southern coastline in Sri Lanka. Primary data were gathered through questionnaires administered to local stakeholders, while secondary data were obtained using mapping techniques and remote sensing tools to analyze land-use changes over time. The findings revealed several negative environmental impacts linked to tourism-driven development. These included unclean and poorly maintained beaches, blocked or restricted access to the shoreline, increased coastal erosion, heavy pedestrian movement in sensitive areas, contamination of inland water sources, and significant waste management issues. The researchers further noted that inadequate oversight by land conservation authorities and limited engagement from the tourism sector particularly in the years following the 2004 tsunami have contributed to the persistence of these environmental challenges in Hikkaduwa.

Kirishanthan (2022) has studied on Physical and Social Vulnerability to Coastal Erosion: An Assessment of Kalutara coastal belt, Sri Lanka. The study area is based on the coastline between the Kalu river mouth and the Bolgoda river mouth. The researcher has calculated the Coastal Vulnerability Index (CVI) and Social Vulnerability Index (SVI). According to CVI, the entire study area was classified into five risk levels. Nearly 8116.339 square meters of the area represented very high risk, 3986.947 square meters of the area represented highly risky, 628.0819 square meters of the area represented moderate, 1585.896 square meters of the area represented low, and 5081.386 square meters of the area represented very low respectively. According to SVI, the study found that the coastal areas in Kalutara North are more vulnerable and at risk of both physical and social vulnerabilities to coastal erosion. Amarasinghe (2020) had done the study about Intensity of Coastal Erosion in Sri Lanka: The Case of Southwestern coastal sector. Southwestern coastal sector is referred to as the coastal zone that extends from Colombo to Galle and the total length of the southwestern coastal sector was 155 kilometers (CCD, 1986). The researcher used both primary and secondary data collection methods to do this study. Interviews, informal discussions, questionnaire surveys and field observations were used as primary data collection methods and printed materials, and conference proceedings were used as secondary data collection methods. Shoreline erosion had been calculated in two main methods; Net erosion in meters per year (m/yr) and Net loss of land in square meters per year (m2/yr). The primary environmental effects of the process of increasing shoreline erosion in the Southwestern Coastal sector are the alteration of the equilibrium coastal environment through changing morphological features, the degradation of coastal aquatic and terrestrial ecosystems, the decline in the quality of estuarine-dependent habitat, and the reduction of near shore water quality and change in its volume.

Himaya and Asmiya (2021) studied on Coastal Erosion in Sri Lanka – Causes and Management. Both quantitative and qualitative evaluations of coastal monitoring efforts, remote sensing and GIS tools were applied for this study. Depending on the sample survey in 2015, researchers identified some causes and consequences of coastal erosion; water breaking, tourism activities, destruction of coral reefs, unnecessary constructions and removing sand from the coast. Coastal landforms are extremely dynamic. Numerous development schemes have been constructed along the shoreline, putting a great deal of pressure on it. This can result in a variety of coastal dangers, including sea erosion, seawater intrusion, coral bleaching, and coastline changes. In fact, management of coastal erosion is linked with various planning and rules and regulations such as high-risk area identification and rearranging structure types in terms of buffer zones, concerning easiness to relocate and environmental impact assessment. The use of a sea wall as an alternative to sea erosion is considered a low-cost option.

Weerasekara and Illeperuma (2024) conducted a study titled Shoreline Change Detection and Future Prediction for the Southwestern Coastline of Sri Lanka. The research focused on analyzing shoreline dynamics across the southwestern coastal region over three distinct time periods: 1988–2023, 1988–2001, and 2001–2023. The objective was to quantify shoreline change rates, develop detailed erosion and accretion maps, and predict future shoreline positions for the years 2034 and 2044. The analysis was based on multispectral Landsat satellite imagery spanning 35 years, from 1988 to 2023. To delineate shorelines and evaluate change trends, the researchers used the Normalized Difference Water Index (NDWI) and the Digital Shoreline Analysis System (DSAS). Through DSAS, they calculated key statistical indicators such as the Shoreline Change Envelope (SCE), Net Shoreline Movement (NSM), End Point Rate (EPR), and Linear Regression Rate (LRR). Their results revealed that several coastal areas including Kalutara, Beruwala, Hikkaduwa, Kahawa, and Galle experienced severe erosion, consistent with regional vulnerability assessments. The study also highlighted that rising population density and increasing human activities within the coastal zone have intensified shoreline degradation, making erosion a dominant and escalating concern in the region.

The devastating effects of the tsunami were particularly pronounced in coastal areas already experiencing environmental degradation due to human activities such as the removal of sand dunes, coral reefs, and coastal vegetation. Following the tsunami, the Coastal Resources Management Project (CRMP) conducted a comprehensive damage assessment, which has revealed that several coastal protection structures along the southwest coast were severely damaged, and numerous coastal stretches and sand spits had undergone extreme erosion (CZ&CRMP, 2024). These findings underscored the urgent need for sustainable coastal management practices to mitigate future erosion risks and enhance resilience against natural disasters.

Thus, coastal erosion in Sri Lanka is a multifaceted challenge driven by both natural and human-induced factors. The rate of erosion has increased due to anthropogenic interventions, infrastructure development, climate change, and the growing population density in coastal areas. Despite significant financial investments in coastal management, the persistent threat of erosion continues to impact the livelihoods of coastal communities and the broader economic landscape of Sri Lanka.

Addressing this growing challenge and safeguarding the coastal heritage for future generations requires a holistic and well-coordinated approach. This approach must integrate climate adaptation strategies, sustainable coastal conservation practices, and robust policy and governance frameworks. Effective management of coastal erosion is vital not only for protecting human lives and livelihoods but also for guiding sustainable development within coastal zones. Moreover, a clear understanding of erosion dynamics supports evidence-based decision-making, which is increasingly critical as environmental and climatic pressures continue to intensify.

2. MATERIALS AND METHODS

2.1 Study Area

Hikkaduwa is one of the major towns of Galle District in the Southern province of Sri Lanka. Around 4% of the total land area of Galle district belongs to the Hikkaduwa Divisional Secretariat (DS) and it consists of 65 square kilometers and 97 GNDs (Resource Profile, 2020). The study area is situated approximately 100 kilometers south of Colombo and 15 kilometers north of Galle, positioned at a latitude of 6°09` N and a longitude of 80°08` E. In terms of its relative location, the Hikkaduwa area is bordered by Ambalangoda DS from the north, Kadawath Sathara DS from the south, Gonapinuwala and Baddegama DS from the east and the Indian Ocean from the west. Hikkaduwa area coastline that extends for about 24 kilometers was one of the main areas affected by the Tsunami disaster that struck on 26th December 2004.

Hikkaduwa DS belongs to the south-western coastal lowland region. Most of the areas in Hikkaduwa DS are flatlands below the 100-foot contour line. Water bodies of Hikkaduwa DS include the Thelwatta River, Thuduwegoda Canal, Mawakada Canal and Rathgama lagoon. Based on the existing land conditions in the study area, physical as well as human activities have been widely distributed. Geological survey of the entire region revealed that it is composed of different rock types of Pre-Cambrian period. Red Yellow Podzolic soil with hard Lateritic and Red Yellow Podzolic soil with quartz are prevalent throughout the area. Semi-loamy to loamy and well-developed mixed soils were found from the river valleys and water areas. The study area belongs to the lowland wet zone. Therefore, there is significant rainfall throughout the year. The expected annual rainfall is 1,575 mm. There is a greater than 75% probability of receiving this annual rainfall. The annual mean temperature is 26.9 Celsius. The total population of the study area is 116, 247 including 60,186 male and 56,061 female (Resource-Profile, 2020).

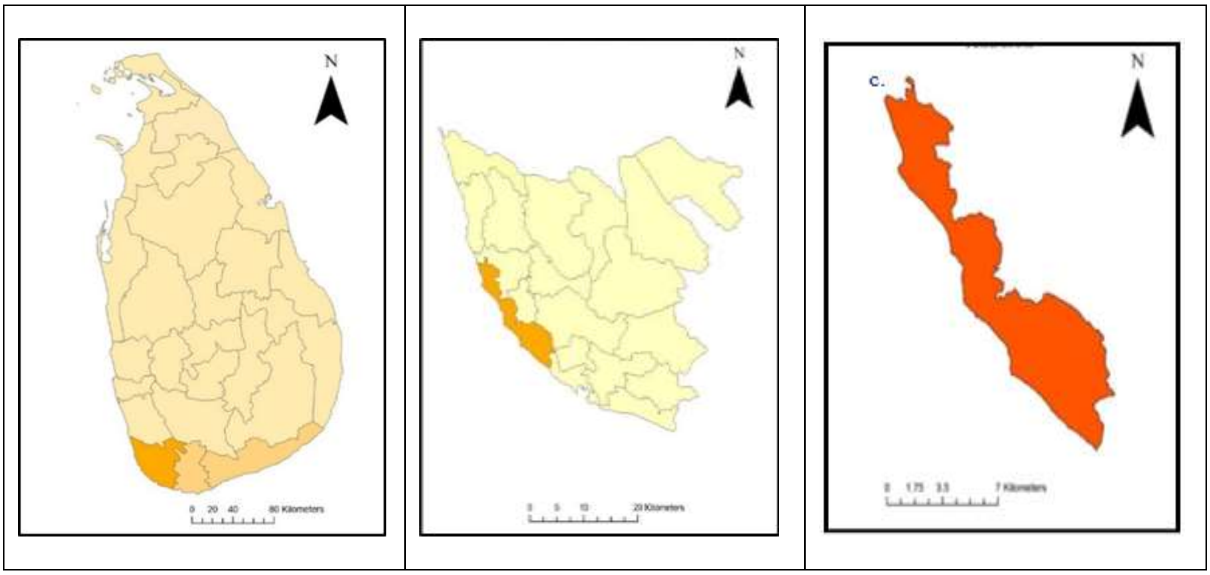

Figure 1: Study Area. Location of Galle District in Sri Lanka (a), Location of Hikkaduwa DSD in Galle District (b), Hikkaduwa DSD (c).

Source: Created by Author using 1:50000 Digital Data from the Survey Department of Sri Lanka, 2018

3.2 Data Collection Methods

Both primary and secondary data collection methods were used to collect the data in the study, incorporating both qualitative and quantitative data. In order to obtain the primary data, two main methods; questionnaires and interviews were carried out.

100 people were selected as the sample purposively including 75 local residents and the 25 foreigners. The local sample was further divided into 50 of the community members from the study area, 15 individuals engaged in the tourism industry and 10 relevant government officials. The government representatives included the officials from the Hikkaduwa DS Office, particularly from the planning unit and the land unit, as well as personals from the Disaster Management Centre (DMC), Galle.

Previous research papers and journals, annual government reports, non-government organization and environmental organization reports and geographic tools such as satellite images and remote sensing data, 1:50000 digital data from Survey Department of Sri Lanka, 2018 were used as secondary data collection methods. Satellite images of Hikkaduwa DS from 2004, 2005, 2014, and 2024 were downloaded by the researcher using the United States Geological Survey (USGS), specifically obtaining Landsat 5 and 8 images. All satellite images were in Landsat Level 2 Science Product quality (USGS, 2025). Geographic tools like raster calculator and image analysis were used to create maps in the study. Other secondary data collection methods mentioned previously were used to identify scientific and historical perspective related to the study.

Table 2: Detailed Information of Utilized Landsat Images

Sensor Type	ID	Acquisition Date	Path/ Raw
Landsat 5 TM	LT05_L1TP_141056_20040227_02_T1	27/02/2004	141/056
Landsat 5 TM	LT05_L2SP_141056_20050824_02_T	24/08/2005	141/056
Landsat 8 OLI/TIRS	LC08_L1TP_141056_20141207_02_T1	07/12/2014	141/056
Landsat 8 OLI/TIRS	LC08_L1TP_141056_20241218_02_T1	18/12/2024	141/056

3.3 Data Analytical Techniques

The data which were collected from both primary and secondary data collection methods were analyzed by using different analytical techniques. Digital Shoreline Analysis System (DSAS) was used to identify the loss of coastline in Hikkaduwa area and descriptive analysis was used to define the causes of coastal erosion in the study area. Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) analytical techniques were used to identify the persistent challenges of coastal erosion in Hikkaduwa DS. Charts and graphs were represented by using Microsoft Excel 2013 office package and GIS analysis such as DSAS, NDVI and NDBI were done by using ArcGIS Pro software. GIS analysis aimed to create the location of the study area, DSAS technique, NDVI analysis and NDBI analysis.

NDVI serves as a vegetation index that provides insights into the density and existence of plant life on the Earth's surface (Delarizka and Sasmito, 2016). The NDVI value varies from -1 to +1 range. Higher value of NDVI reflects higher Near Infrared, associated withdense greenery (Kshetri, 2018).

NDVI	(NIR - RED) / (NIR + RED)
NIR	The Reflectance of Near Infrared Band
RED	The Reflectance of Red Band

After the extraction of the study area, NDVI was applied to each satellite image. In the next phase, Map Algebra was used in raster calculator in ArcGIS Pro software. Using the following equation, NDVI analysis for the study area was conducted effectively.

For Landsat 5	NDVI = (BAND 4 – BAND 3) / (BAND 4 + BAND 3)
For Landsat 8	NDVI = (BAND 5 – BAND 4) / (BAND 5 + BAND 4)

NDBI value lies between -1 to +1 range. Negative value of NDBI indicate water bodies and whereas higher value represent built-up areas in the relevant area Vegetation exhibits low NDBI values (Kshetri, 2018).

NDBI	(SWIR - NIR) / (SWIR + NIR)
SWIR	The Reflectance of Short Wave Infrared Band
NIR	The Reflectance of Near Infrared Band

After the extraction of the study area, NDBI was applied to each satellite image. In the next phase, Map Algebra was used in raster calculator in ArcGIS Pro software. Using the following equation, NDBI analysis for the study area was conducted effectively.

For Landsat 5	NDBI = (BAND 5 – BAND 4) / (BAND 5 + BAND 4)
For Landsat 8	NDBI = (BAND 6 – BAND 5) / (BAND 6 + BAND 5)

3. RESULTS AND DISCUSSON

3.1 Causes of Coastal Erosion

Coastal erosion was caused by both natural and anthropogenic activities. Coastal environments can be significantly shaped and changed over time by these natural factors, either independently or in combination. Coastal erosion is significantly exacerbated by anthropogenic activities, both directly through mining, construction, and pollution and indirectly through climate change with rapid growth of population and urbanization. The figure 2 shows the causes of coastal erosion in Hikkaduwa. Among the entire sample, 75 local respondents participated in the survey below. Illegal sand mining stands out as the most significant cause of coastal erosion with 84 percent. Effect of coral reef degradation follows with 76%. Tourism activities account for 61 percent and wave actions and currents have a significant impact with 26%.

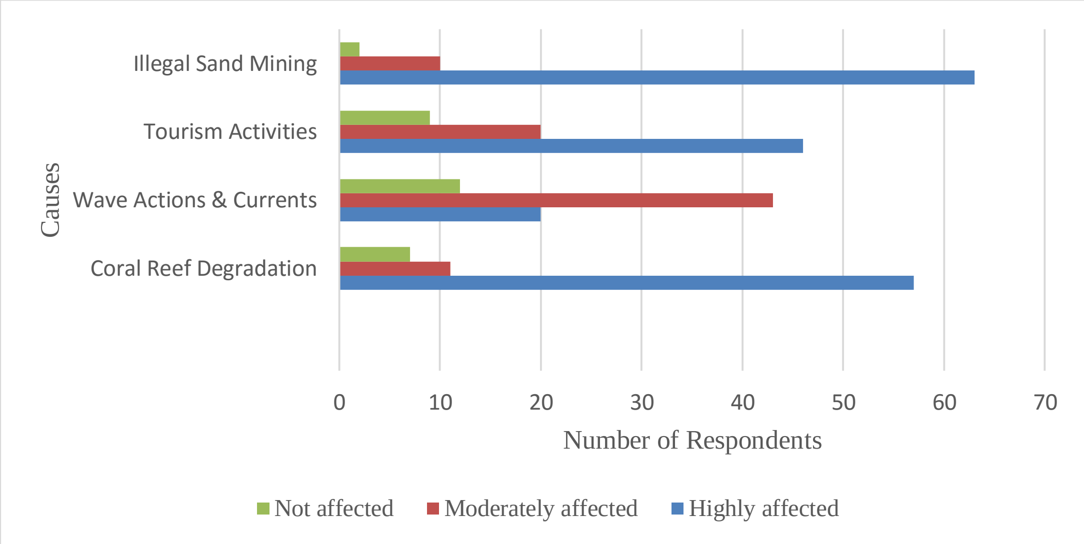

Figure 2: Local Residents' Perceptions of Causes of Coastal Erosion

Source: Created by Author based on Questionnaire Survey & Interview; 2024

Wave Actions and Ocean Currents

Wave action and ocean currents play a significant role in shaping coral reef ecosystems. The Hikkaduwa area is directly exposed to the southwest monsoon from May to September each year. During this period, extreme weather events such as tropical cyclones and intense monsoonal rainfall have become increasingly destructive, leading to severe coastal erosion and elevated sedimentation levels in near-shore water areas. Strong wave activity causes direct physical damage to marine ecosystems, particularly coral reefs, while ocean currents transport large volumes of sediments and materials over considerable distances. As well as, seasonal wave dynamics occasionally allow sea waves to overtop the coastline and penetrate inland areas. This phenomenon often disrupts transportation, resulting in frequent traffic congestion along the Colombo–Kataragama main road, especially in the Kahawa, Telwatte, and Akurala areas. (Interview, 2024).

Coral Reef Degradation

Coral reef degradation refers to the deterioration of coral reef ecosystems. Coral reefs in Sri Lanka are categorized into three habitat types. They are true coral reefs, consisting of live corals as well as calcareous substances, sandstone reefs, and rocky reefs. Hikkaduwa coastline has severely experienced significant degradation over the years. Data collected by using interview revealed that coral bleaching and overfishing activities have directly harmed coral reef ecosystems in the area. In addition, the Tsunami in 2004 contributed to the degradation of the coral reef ecosystems in Hikkaduwa. Destructive fishing practices including, bottom set netting, stepping, dynamiting, coir industry, glass bottom boat maneuvering, and excess sediment and freshwater influx are the major causes responsible for the degraded situation on the Southern coast (Synthesis Report on Coastal Habitat, 2014). Coral bleaching incidents were also increased due to rising ocean temperature related to climate change.

Tourism Activities

Tourism is the key industry in the study areaattracting both local as well as foreign tourists. Tourism activities in Hikkaduwa are based on water-based experiences, nature exploration and cultural activities. Swimming and Relaxing, Surfing, Snorkeling, Scuba Diving, Glass-Bottom Boat Riding, Kayaking and Canoeing, Water Skiing and Jet Skiing, Windsurfing, Turtle Watching, Fishing Tours, Cultural and Nature Tours are the most popular tourism activities in Hikkaduwa area (Interview, 2024). 25 Foreign tourists shared their preference of tourism activities in Hikkaduwa. The collected data is shown as a percentage in the Fig 3.

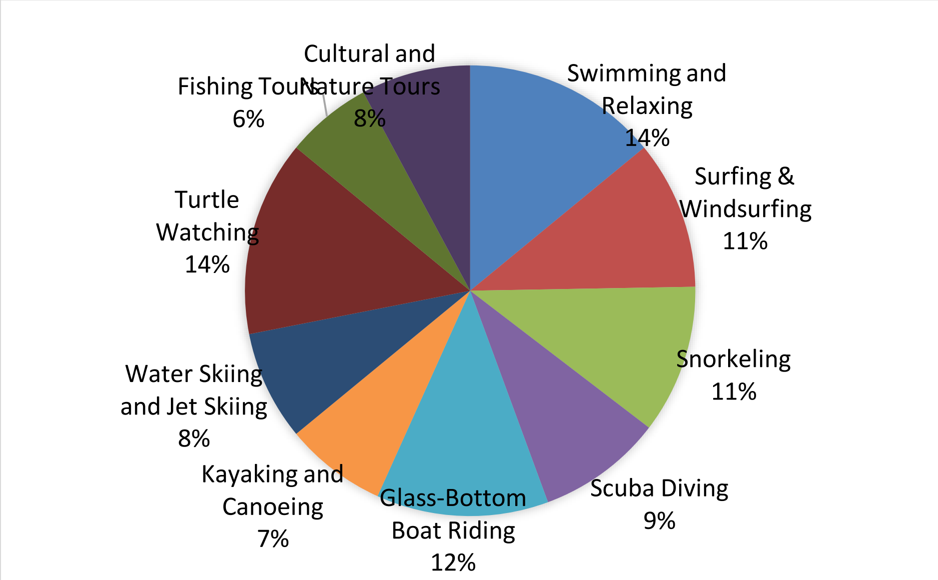

Figure 3: Preferences of Tourism Activities
Source: Field Survey; 2024

Based on the survey, it could be identified that from November to April is the peak tourist season and from May to October is the off-tourist season. Peak tourist season can lead to overcrowding on coastline and the entire marine environment. Pollution and disposal of garbage also was increased in related to tourism activities in the study area. Plastic waste, sewage and litter ending up in the ocean, could cause harm directly to the shoreline.

Illegal Sand Mining

Sand mining is the extraction of sand from beaches, rivers or sea-beds, when it is done unsustainably or without proper permits. Sand is the crucial element in the natural structure of the beaches. Sometimes the government needs to intervene by constructing seawalls and breakwaters due to the impacts of illegal sand mining. Without sand deposits to replenish the beaches, the coastline becomes more susceptible to erosion from wave action. The depletion of sand from the beach further accelerates the loss of shoreline. A lack of sand deposits in the shoreline area or offshore areas can lead to increased sedimentation in water. Although sand mining is an economically valuable livelihood activity, it may disturb some of the major income sources of the study area. Due to illegal sand mining, tourism activities as well as fishing activities collapsed. Illegal sand mining affected coral reefs, fish population including the entire marine environment. Depletion of coral reefs and the decline in fish population could lead to disruption of the local livelihood activities. If there is no rich sand nutrient in the shoreline, coastal vegetation also can be severely damaged. According to the participants' opinions, there was no healthy coastal vegetation in the entire study area.

3.2 Long-term Challenges of Coastal Erosion

Change in Shoreline

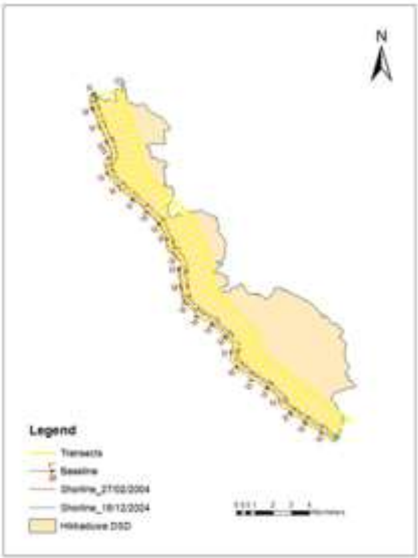

Figure 4: Change the Shoreline in Hikkaduwa DS from 2004-2024
Source: Created by Author using 1:50000 Digital Data from the Survey Department of Sri Lanka, 2018

To further increase the precision and level of detail of shoreline analyses, machine learning algorithms and high-resolution satellite imagery such as Sentinel-2 or commercial satellites are also predominantly used (El-Asmar and Hereher, 2011). In recent years, advanced methodologies such as the DSAS have allowed researchers to measure shoreline changes with enhanced accuracy through statistical models that calculate rates of erosion and accretion over time (Thieler et al., 2009). Shorelines for the years 2004 and 2024 were generated and mapped in using ArcGIS pro software. A significant change over the years was observed around the study area. The Fig 4 illustrates the spatial and temporal variations in the shoreline position along the coastal region of Hikkaduwa DS over the past two decades.

Loss of Vegetation

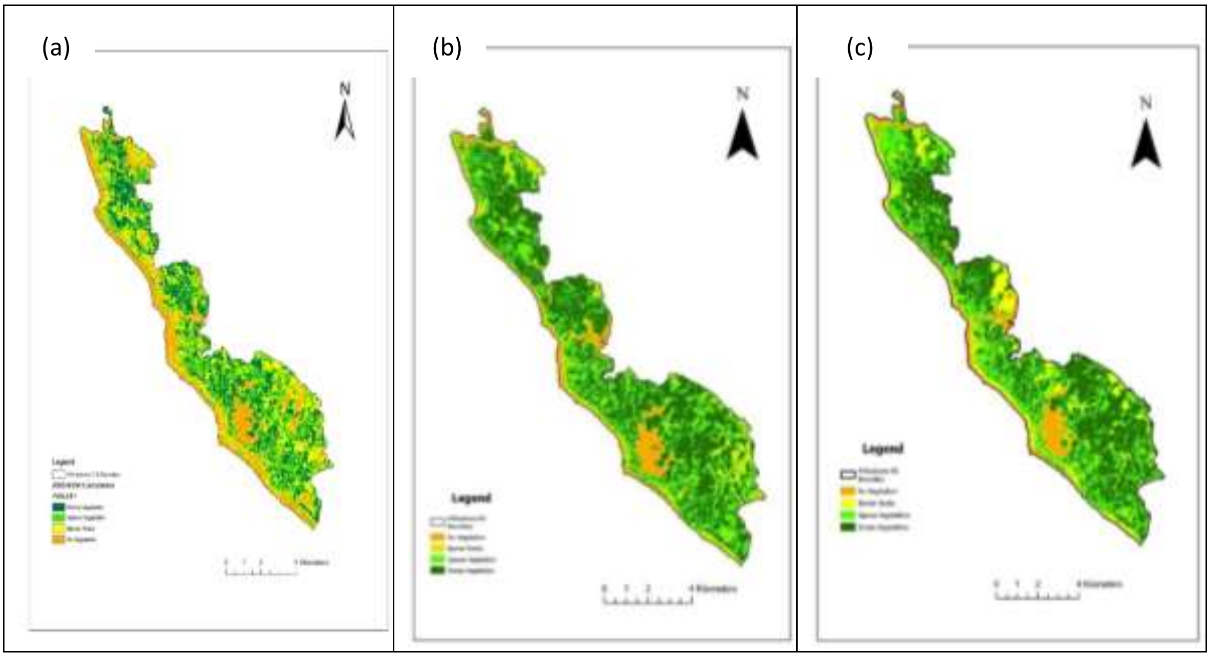

Figure 5: NDVI Analysis for Hikkaduwa DS. 2005 (a), 2014 (b), 2024 (c).
Source: Created by Author using 1:50000 Digital Data from the Survey Department of Sri Lanka, 2018 and USGS Data

A comparison of the vegetation cover maps from 2005, 2014, and 2024 reveals significant changes in the vegetation, particularly along the shoreline. The 2005 map indicates moderate vegetation cover near the shore, suggesting a relatively stable and natural coastal ecosystem. However, by 2014, there is a noticeable decline in vegetation, primarily driven by the rapid expansion of built-up areas to accommodate the increasing tourist traffic in the area. By 2024, the decrease in vegetation cover is even more pronounced, highlighting the ongoing and intensified pressures from development, coupled with the lack of effective land-use planning and environmental conservation measures. This progressive loss of vegetation has important ecological impacts due to the loss of resilience to coastal erosion and a reduction of biodiversity in the region, ultimately degrading the coastal environment. In 2004, the Indian Ocean tsunami severely damaged the vegetation in Hikkaduwa, a coastal town in Sri Lanka. The coastal vegetation was severely damaged by the tsunami waves and surges, particularly the mangroves, coastal forests, and plant species that are critical to the local ecosystem. Saltwater inundation caused by the tsunami led to the salinization of soil, rendering it inhospitable for many freshwater and salt-sensitive plant species. Mangrove forests, which act as natural buffers against coastal erosion, were also damaged severely, compromising their ability to regenerate quickly due to the destruction of root systems and the deposition of debris. The destruction of vegetation has had cascading effects on the local wildlife, as many animals have lost their habitats and food sources. Overall, the vegetation damage in Hikkaduwa serves as a stark reminder of the vulnerability of coastal ecosystems to extreme natural events and the long-term environmental consequences of such catastrophic occurrences.

Improper Coastal Development

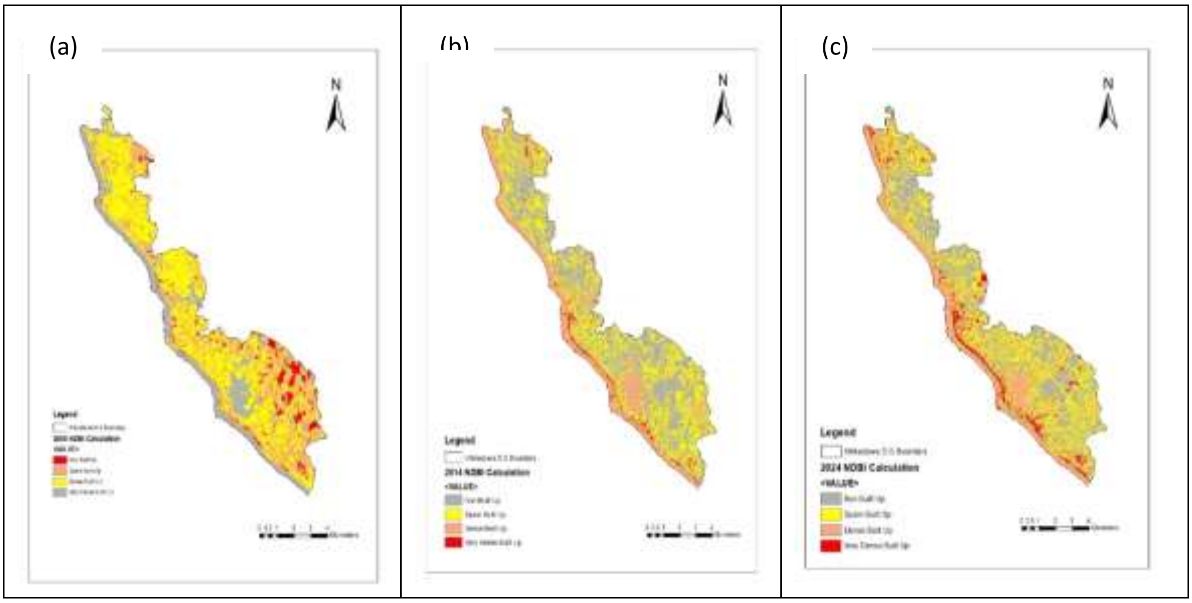

Figure 6: NDBI Analysis for Hikkaduwa DS. 2005 (a), 2014 (b), 2024 (c).

Source: Created by Author using 1:50000 Digital Data from the Survey Department of Sri Lanka, 2018 and USGS Data

The maps of the years 2005, 2014 and 2024 show the changes that have occurred in the built-up areas in the study area. The building density was minimum in 2005 compared to the years 2014 and 2024. Rapid growth of urban facilities and tourism industry in the study area built up facilities were increased. Most of the buildings were established in the lower part of the DS areas like Wawlagoda, Wewala, Narigama, Modara Patuwatha and Thiranagama. The aftermath of the 2004 Indian Ocean tsunami in Hikkaduwa exposed significant issues related to improper coastal development, which exacerbated the region’s vulnerability to future natural disasters. The construction of hotels, resorts, and other infrastructure close to the coastline displaced native vegetation, reducing the natural protection offered by these ecosystems. The most of development projects ignored environmental regulations and found short-term gains without realizing the long-term consequences of building in ecologically sensitive coastal zones. This overdevelopment, often fueled by tourism-driven demand, contributed to increased vulnerability. As the demand for beachfront properties grew, the prioritization of economic gain over environmental sustainability led to the creation of artificial barriers between communities and their natural surroundings. The improper coastal development in Hikkaduwa thus highlights the critical need for sustainable, well-regulated urban planning that integrates ecological considerations to safeguard both human populations and the natural environment in the face of future environmental challenges.

4. CONCLUSION

This research provides a comprehensive study of the causes of coastal erosion in Sri Lanka, with a particular focusing on Hikkaduwa DS in Galle district. The main objective of this study was to examine the identify causes of coastal erosion in the Hikkaduwa DSD of the Galle District over the period from 2004 to 2024. This research was carried out using descriptive analysis derived from interviews and questionnaire surveys conducted with relevant stakeholders. Additionally, the study sought to identify the long-standing challenges associated with coastal erosion in Hikkaduwa DS during the same period. To achieve this, shoreline changes were analyzed using the Digital Shoreline Analysis System (DSAS) for the years 2004 to 2024, while Normalized Difference Vegetation Index (NDVI) and Normalized Difference Built-up Index (NDBI) techniques were applied to evaluate land-cover dynamics from 2005 to 2024. The results suggested erosion trends in most areas, with Narigama and Akurala identified as facing particularly significant erosion. The study effectively visualized the change of shoreline, NDVI and NDBI in the study area. Although the study provided findings, further research should be conducted in the area using more advanced techniques such as LiDAR, Drone based Photogrammetry to improve the predictions and sustainable development and effective management of the entire Hikkaduwa DS and its related coastal line in Galle district of Sri Lanka. The combined impact of climate change, unregulated urban development, overexploitation of coastal resources, and environmental degradation has led to an ongoing crisis that threatens the livelihood of local communities, the health of the coastal ecosystem, and the economic well-being of the area. The solution to these challenges lies in adopting a more integrated and sustainable coastal management approach. Only through collaborative efforts by local communities, the government institutions, and environmental organizations can enable Hikkaduwa area to reverse the presently existing challenges of coastal erosion as well as maintain its coastal cover for future generations.

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