RESEARCH ARTICLE

MEDIA KONSERVASI
SCIENTIFIC JOURNAL IN CONSERVATION OF NATURAL RESOURCES AND ENVIRONMENT

Factors Influencing Coastal Flooding from Akurala to Godagama in Sri Lanka

Ashvin Wickramasooriya and Hahsika Ravihari

Department of Geography, University of Peradeniya, Peradeniya, 20400, Sri Lanka

Article Info:
Received 03 June 2024
Revised 18 October 2024
Accepted 04 November 2024

Corresponding Author:
A. K. Wickramasooriya
Department of Geography,
University of Peradeniya,
Peradeniya, 20400, Sri Lanka
E-mail:
awickramasooriya@gmail.com

Abstract

Over the past decade, the Southwest coast of Sri Lanka has experienced recurrent coastal floods, particularly in the stretch from Akurala to Godagama. This study, spanning from 2010 to 2020, seeks to unravel the factors influencing these floods, filling a void in existing research on the subject. Employing topographic maps, field observations, and bathymetric data from the Lanka Hydraulic Institute and Coastal Conservation Department, the research delves into geomorphological features and elevation variations in the study area. Findings indicate that high elevation in the Ambalangoda to Akurala and Godagama to Hikkaduwa regions contributes to coastal flooding, as these areas are elevated above the mean sea level. The bathymetric analysis exposes closely spaced contours and steep slopes, exacerbating flooding when waves collide with the coastline. The absence of mangroves amplifies the impact, distinguishing the study area from its neighbouring regions. Socioeconomic consequences include road closures, accidents on the Galle-Colombo main road in 2020, and adverse effects on fisheries and tourism. Environmental impacts encompass coastal erosion, degraded water quality, coral bleaching, and saltwater intrusion. While artificial structures like rock barriers mitigate flooding, the study underscores the interplay of land morphology, bathymetry, land use, and climate influencing coastal flooding along the Akurala to Godagama coast.

Keywords: bathymetry, coastal flooding, digital elevation model, geomorphology

1. Introduction

Coastal zones serve as vital economic and ecological hubs that support fisheries, commerce, navigation, and recreation. However, they are threatened by erosion, which can disrupt the entire ecosystem. Erosion is driven by natural processes such as wind, waves, tides, and human activities along the coast. As sea levels rise, waves gain more energy and intensify erosion [1], [6]. Coastal flooding occurs during high tides and storms, pushing inland water.

Repercussions of coastal flooding present challenges, particularly because the extent of flooding can vary widely within a small geographical area, contingent on local topography and bathymetry [2]. Additionally, the impacts of flooding on residents and businesses hold greater significance for planning and response than merely the geographic extent. The social impact of flooding can differ significantly depending on the distribution of people, infrastructure, and economic activity along the coast. Thus, assessing flood effects requires localized measures of inundation and its consequences for coastal communities.

A comparison of surge models by de Vries et al. [3] highlighted the importance of accurate wind stress in predicting surges and revealed a tendency to underestimate them. Further research by Williams and Flather [4] emphasized the need for enhanced wind stress and nearshore bathymetric resolution. Anthropogenic activities, such as land use changes and coastal infrastructure, alongside global phenomena, such as climate change, modify coastal hazard responses. Climate change, particularly global warming, may substantially alter the hydrodynamic forcing, sea level, and wave climate, thereby accentuating coastal vulnerability. Socioeconomic conditions, urbanization, and infrastructure significantly exacerbate flood risks, especially in densely populated coastal areas.

The Southwest coastal sector in Sri Lanka suffers from coastal flooding, especially during the southwest monsoon from May to September [6], and human activities such as destroying mangroves, coral, and sand mining influence coastal floods. Ambalangoda to Hikkaduwa stretch faces significant coastal flooding threats, while the adjacent areas are less affected. Understanding the environmental and socioeconomic impacts of flooding is crucial. Therefore, this study focused on identifying the main factors influencing coastal floods in the study area.

2. Materials and Methods

2.1. Study Area

The coastal sector from Ambalangoda to Hikkaduwa lies in the Hikkaduwa Divisional Secretariat Division in the Galle district of the Southern Province in Sri Lanka (Figure 1). The extent of the study area was approximately 65 km^2, and the length of the coastal sector was approximately 24 km. The Galle District receives a significant amount of rainfall throughout the year. This climate is Af, according to the Köppen-Geiger climate classification. The annual high temperature 30.32^{0}C and annual low temperature 24.96^{0}C in Galle, and the average annual rainfall is 100.54 mm [7].

Beaches, water bodies connected to the sea, home garden areas, scrublands, mangroves, marshy lands, cultivation, and built-up areas constitute the land-use patterns identified in this coastal area. Furthermore, man-made structures such as fishing harbors, which have been under construction in the Peraliya area since 2015, footpaths constructed from the Aural to Madampagama with high seawalls, and rock barriers can be seen in various places in the sea around Hikkaduwa and Ambalangoda. The fishing industry, boat manufacturing, tourism, cement production, and agriculture are the main livelihoods in this densely populated coastal area (Hikkaduwa Divisional Secretariat Office) [8] (Figure 1).

To better understand and compare the flood situation in the study area, it was divided into segments: 1–Hikkaduwa to Godagama, 2–Godagama to Akurala, and 3–Akurala to Ambalangoda. The analysis revealed that the coastal stretch from Aural to Godagama was the most severely affected by recent floods (Figure 2). Consequently, this study compares the conditions that contribute to coastal flooding in these segments. Segment analysis aims to identify the factors influencing flood severity, such as topography, land use, drainage infrastructure, and historical weather patterns.

Segmenting the study area pinpoints localized issues and simplifies interventions. For example, the Aural to Godagama stretch may have unique characteristics such as lower elevation or inadequate drainage systems that exacerbate flooding. Furthermore, comparing these segments allows for a more targeted approach to flood management and mitigation. Understanding the distinct challenges of each segment can lead to more effective and sustainable solutions. The findings of this study will be crucial for local authorities and stakeholders in planning and implementing measures to reduce the risk and impact of future coastal floods, thereby enhancing the resilience of affected communities.

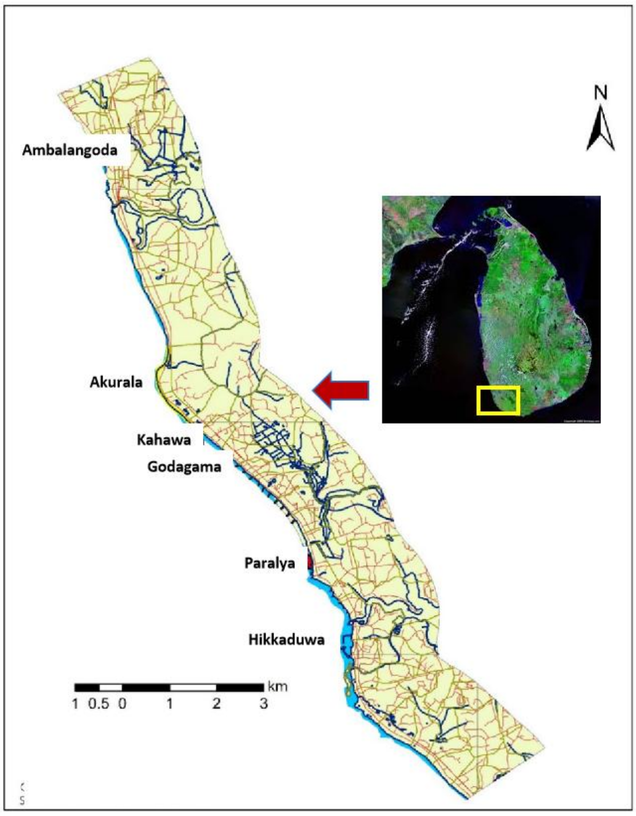


Figure 1. Study area (Coastal stretch from Ambalangoda to Hikkaduwa).

Figure 2. Coastal flooding experience in the recent past (a and c are near Kahawa and b is closer to Godagama).

2.2. Material

This study utilized diverse datasets and analytical tools to comprehensively understand the landscape dynamics and interactions between natural and human systems in the region of Sri Lanka. Topographic and land use maps from the Survey Department detailed terrain and land utilization patterns, whereas bathymetric maps from the Lanka Hydraulic Institute provided insights into the underwater topography crucial for coastal dynamics. Precipitation data from the Meteorological Department enriched the analysis by considering the impacts of climate variability on erosion, soil moisture, and vegetation distribution.

Socioeconomic statistical data from the Statistical and Census Department offered insights into population distribution and infrastructure development, which are crucial for understanding human-environment interactions. The ArcGIS software facilitated the creation of digital thematic layers, enabling spatial analysis, visualization, and modeling. By integrating these datasets and tools, this study aimed to provide a holistic understanding of landscape dynamics and human-environment interactions, supporting informed decision-making.

2.3. Methodology

This study was initiated to address the pressing research problem of significant coastal flooding in specific areas along the southwest coast of Sri Lanka. Hence, the primary objective of this study was to meticulously identify the pivotal factors influencing coastal flooding in these regions. The areas that have recurrently borne the brunt of coastal flooding in the past were meticulously demarcated. Subsequently, digital thematic layers were meticulously prepared to depict factors that could potentially exacerbate coastal floods. These layers were then meticulously compared to the conditions in areas affected by coastal flooding and those that remained unaffected. Through this comparative analysis, the most influential factors that contribute to coastal flood vulnerability were identified. The essential procedural steps of the study are shown in Figure 3 for clarity and ease of understanding.

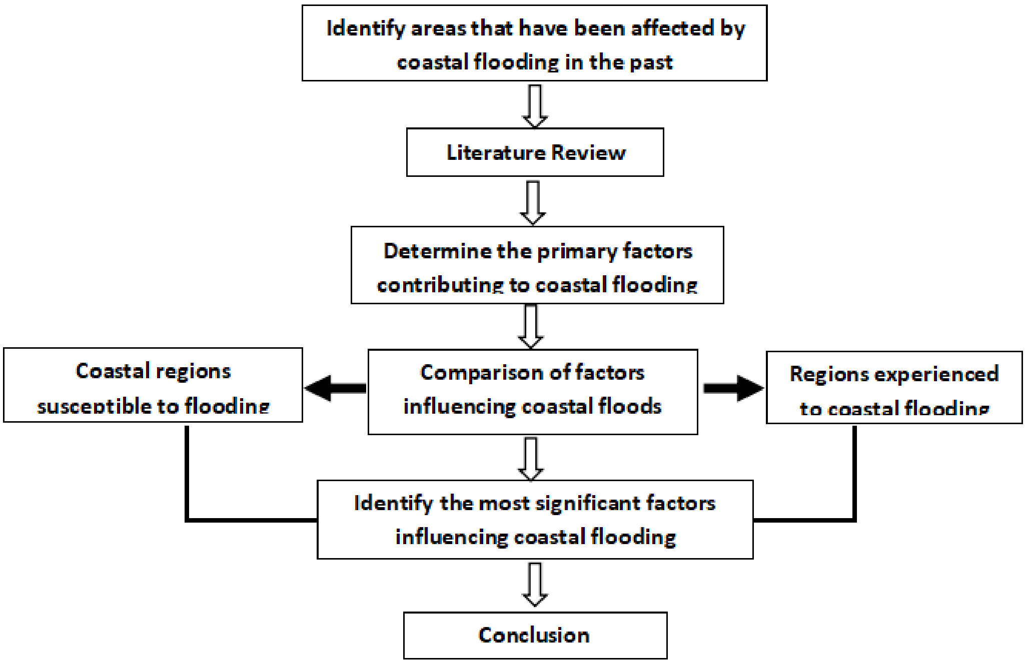


Figure 3. Steps in the research methodology.

2.3.1. Literature review and identification of coastal flooding-affected areas from Ambalangoda to Hikkaduwa

Several previous studies related to the current research have been reviewed to identify the main factors influencing coastal flooding. According to Moore [2], understanding the drivers and consequences of coastal flooding is challenging because the extent of flooding can vary greatly within a small area owing to local topography and bathymetry. The same level of flooding can have vastly different social impacts, depending on the distribution of people, infrastructure, and economic activity. Thus, measuring flood effects requires highly localized measures of inundation and its impact on coastal communities. Using standardized bathymetry and wind forcing, a surge model inter-comparison exercise [3] revealed minimal differences. However, it underscored the importance of accurate wind-stress representation, as all models tended to underestimate the surge.

A tide-surge model introduced by Williams and Flather [4] in the UK also demonstrated the need for enhanced wind-stress compared to the approach by Smith and Banke (1975) [5]. Recent research by Brown and Wolf [9], suggests that this discrepancy may be related to wave effects and the resolution of nearshore bathymetry. Coastal flooding results from elevated water levels due to tides, storm surges, and waves that exceed the capacity of coastal defenses, leading to the inundation of low-lying areas. The genesis of these elements often lies in powerful storms characterized by high winds over the sea. Additional risk factors for deltas and estuaries include heavy precipitation and increased river flow. Socioeconomic factors further exacerbate vulnerability as densely populated coastal areas with significant human settlements and infrastructure investments are particularly at risk. Frequent storms can accelerate coastal erosion and cause flooding, which could also negatively impact beaches by losing land and shorefronts and interfering with coastal tourism [10].

In all countries, artificial nourishment is traditionally used to combat structural erosion on sandy coasts, and this is expected to increase under future climate change. The coral breaks the reef with sharp instruments and digs in the nearshore and low-lying coastal areas. Removing coral from littoral drift contributes to the development of erosion. Based on recent literature and satellite imagery analysis, the coastal stretch from Ambalangoda to Hikkaduwa, specifically from Aural to Godagama, has experienced significant coastal flooding in the recent past (Figure 4).

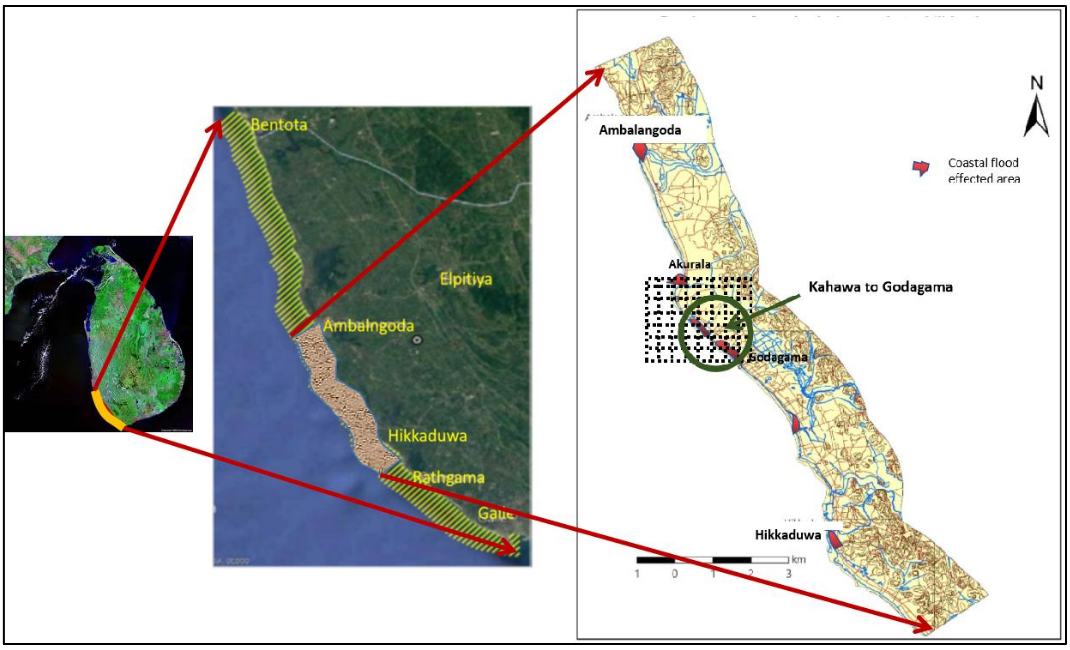


Figure 4. The study area flows along the Southern coast of Sri Lanka from Ambalangoda to Hikkaduwa, which has been severely affected by coastal floods over the last five years.

3. Results

3.1. Determination of Factors that Contribute to Coastal Flooding

Coastal flooding is influenced by several key factors as identified in previous studies. Bathymetry, or underwater topography, affects the flow and accumulation of water and significantly influences the extent of flooding [12]. Coastal geomorphology, which encompasses the physical characteristics of a coast, such as its shape and composition, plays a critical role in determining how water inundates land areas [13]. Land use patterns, including urban development and vegetation cover, impact water absorption and runoff and further shape flood dynamics [13]. Additionally, anthropogenic activities such as the construction of sea walls, piers, and drainage systems, and practices such as coral and sand mining can mitigate or exacerbate the severity of coastal flooding [15].

Therefore, these factors were considered in this study. The increasing risk of low-elevation coastal zones from episodic seashore erosion and hinterland flooding will continue to increase in the coming decades. This hazard is exacerbated by anthropogenic activities (e.g., land use changes, hydrological and coastal infrastructure, land reclamation, and groundwater extraction) and global phenomena such as climate change. Coastal vulnerability indices are valuable for predicting the potential impacts of sea storms by analyzing physical drivers, such as wave height, tidal range, subsidence, and sea level rise. These indices also consider physical characteristics, such as annual shoreline retreat, dune height, and beach slope. Population density, land-use patterns, and socioeconomic conditions influence coastal flooding risks. The extent to which the wave setup contributed to the overall water level was determined by the local bathymetry and coastline configuration. The wave setup also varied with the tidal phases. During high tide, larger waves can approach the shore without breaking because of increased water depth, resulting in a diminished wave setup.

3.1.1. Bathymetry

Similar to how topographic maps depict land features, bathymetry measures the ocean depth relative to sea level. Bathymetric maps show underwater terrain variations and are vital for understanding tides, currents, waves, and their physical and chemical properties, which can differ based on underwater features. Natural events, such as storms, earthquakes, and sediment shifts, constantly change nearshore bathymetry. Bathymetric data help estimate depths and predict the impact of underwater morphology on tides and currents, which are crucial factors for coastal flood hazards. In this study, bathymetry data were used to analyze the influence of seabed morphology on coastal floods in the Aural to Godagama area, with detailed seabed profiles shown in Figures 5, 6, and 7.

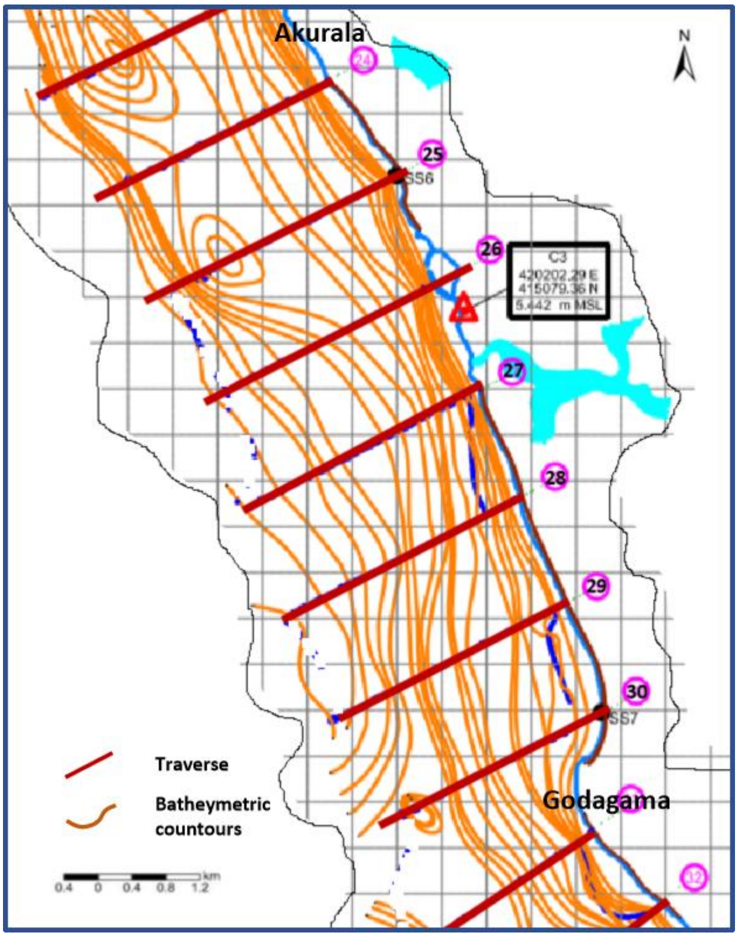
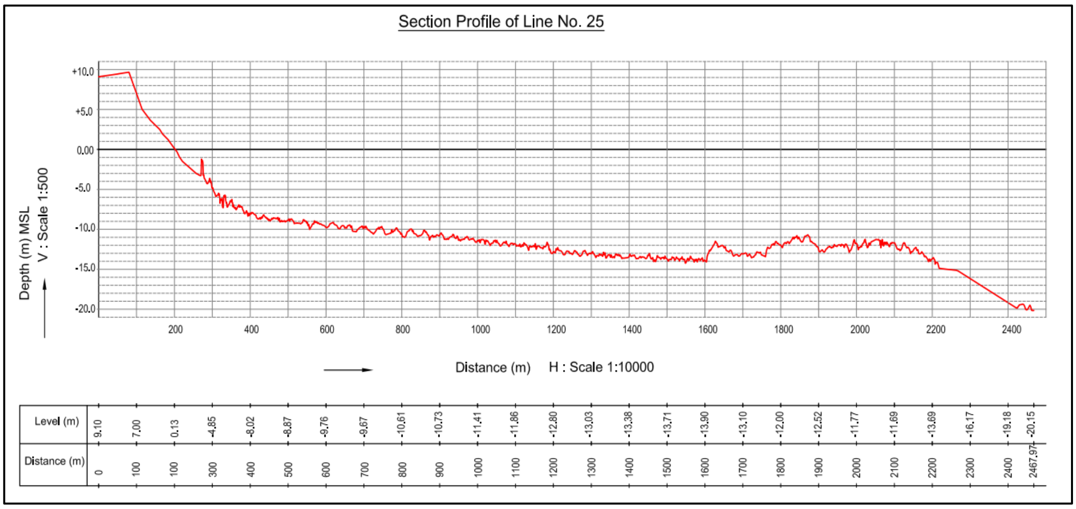
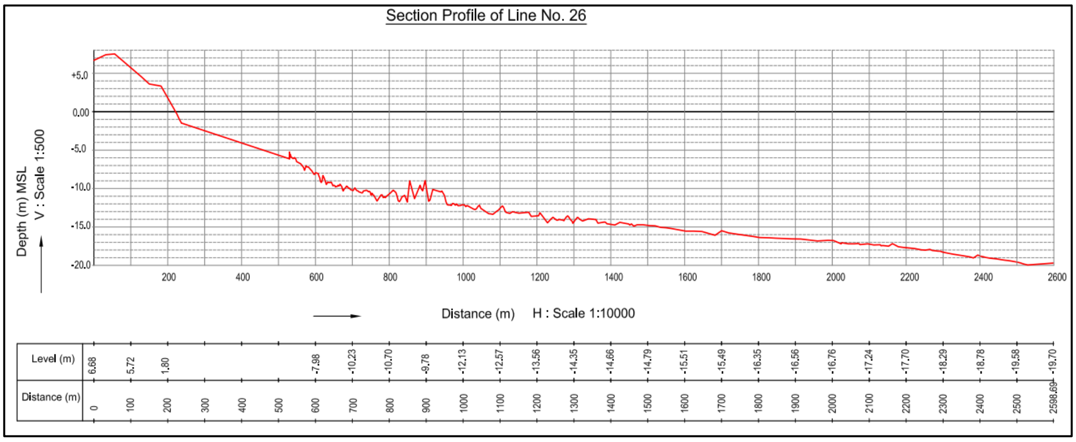


Figure 5. There is variation in the barometric contours from Akurala to Godagama.

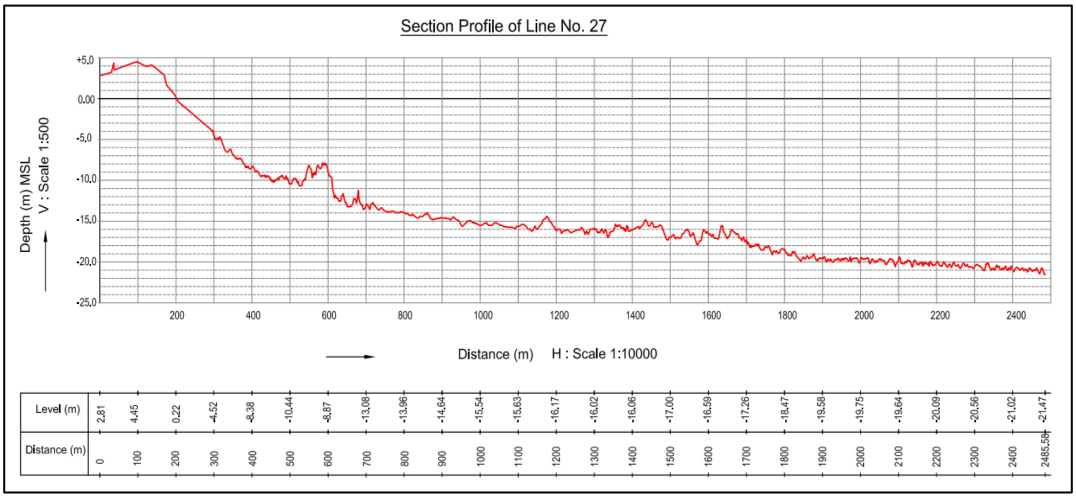
Traverse number 30 reveals a concave slope, where the seabed descends sharply before leveling out. This configuration affects the wave patterns by gradually causing waves to lose energy, reducing their immediate impact on the shoreline. Convex slopes result in higher-energy waves hitting the coast, increasing erosion and flooding risks. Conversely, concave slopes lead to gentler wave action, potentially mitigating immediate erosion and influencing the sediment deposition along the coast. These differences in seabed morphology significantly affect wave dynamics and coastal flood risks. Accurate and detailed bathymetric data are crucial for effective coastal management and hazard mitigation because they provide essential insights into how seabed features influence coastal processes. The transformation of wave conditions from offshore to nearshore is controlled by the seafloor morphology and wind conditions. Smooth sea floors allow waves to propagate towards land, whereas steep and rough sea floors dissipate wave energy, reducing their impact. Nearshore wave data are vital for analyzing coastal floods.



(a)

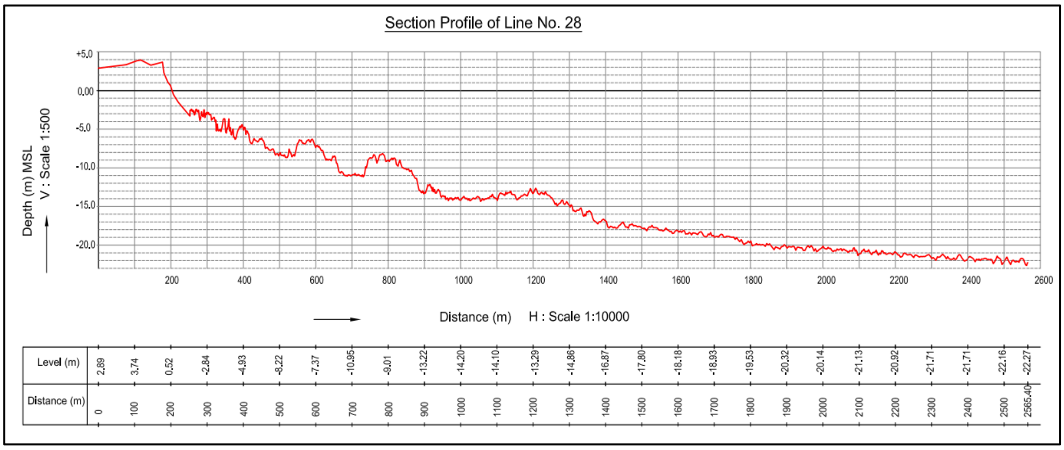


(b)

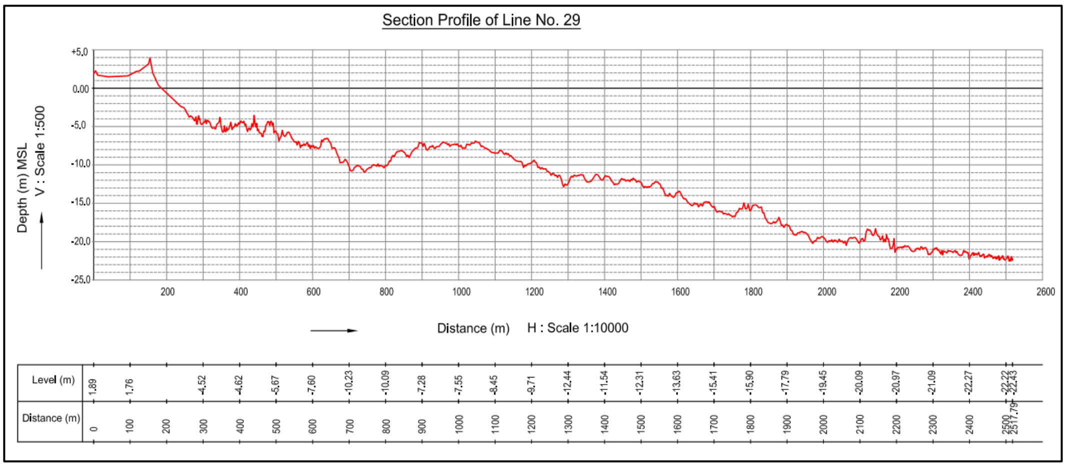


(c)

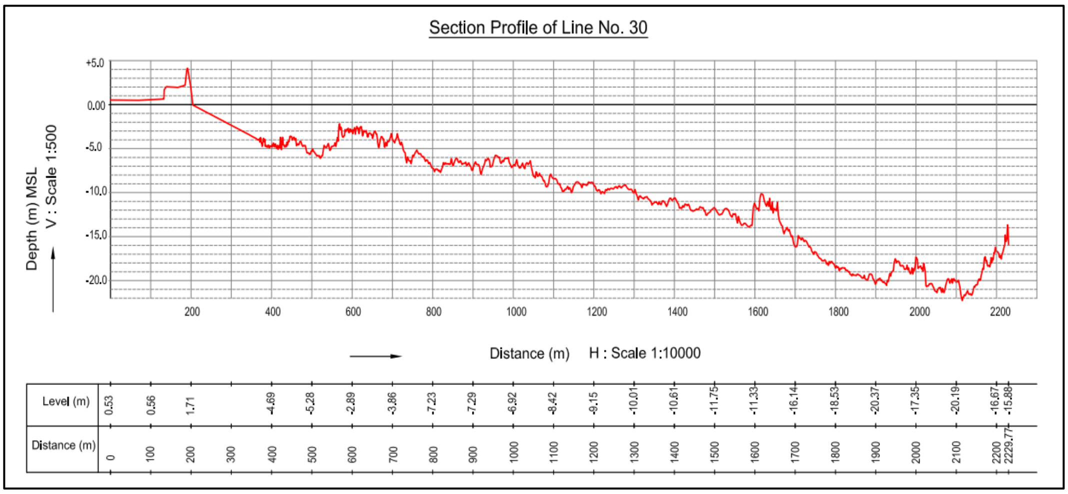
Figure 6. Bathymetric profiles from different traverses show variations in near-seabed morphology; along traverse 25 (a), along traverse 26 (b), and along traverse 27 (c).



(a)



(b)



(c)

Figure 7. Bathymetric profiles obtained at different traverses show that the near-seabed morphology varies; along traverse 28 (a), along traverse 29 (b), and along traverse 30 (c).

3.1.2. Coastal geomorphology

A Digital Elevation Model (DEM) was created to compare the geomorphology in and around the study area, using 1:10,000 topographic maps from the Survey Department of Sri Lanka (Figure 8). According to this DEM, there are high-elevation areas in Hikkaduwa and Ambalangoda, adjacent to the study area. The model also reveals that the Akurala to Godagama area is at elevations of 0m–3.3m, where many coastal flood events have been recorded recently. In contrast, the Ambalangoda to Akurala and Godagama to Hikkaduwa areas are at higher elevations than the Akurala to Godagama area.

3.1.3. Land use pattern

The main land-use types from Ambalangoda to Hikkaduwa can be identified as mangroves, beaches, seagrass beds, estuaries, paddy lands, buildings, and rock outcrops, as shown in Figure 9. To determine whether land-use types influenced the occurrence of coastal floods, the existing land-use types in the three different segments were classified. Similar land-use types were found to exist in both the Ambalangoda to Akurala and Godagama to Hikkaduwa segments, which include rock outcrops, buildings, beaches, erosion protection structures, and mangroves. However, in the Akurala to Godagama segment, there are no significant rock outcrops, although land use types, such as those in the other two segments, can also be found in this area.

3.1.4. Anthropogenic activities

The main anthropogenic activities in the areas from Akurala to Godagama include the construction of coastal erosion protection structures and buildings, coral and sand mining, and the installation of rock barriers. Coral mining is particularly prevalent in and around Hikkaduwa, Japan. In addition, one fishing harbor is located in Peraliya. However, no significant anthropogenic activities existed in the Akurala–Godagama segment. Artificial structures and anthropogenic alterations in this area are illustrated in Figure 10.

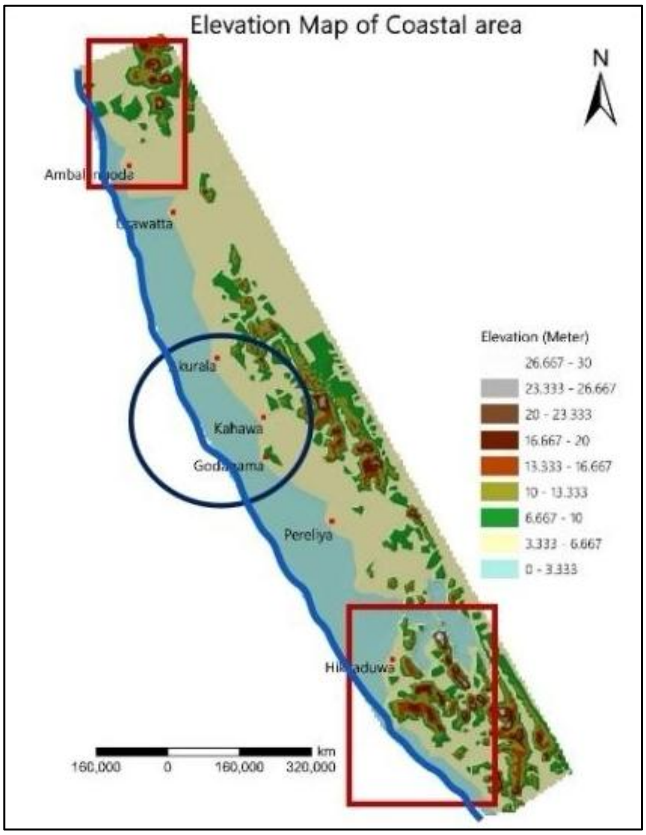


Figure 8. Distribution of geomorphological features based on the Digital Elevation Model (DEM).

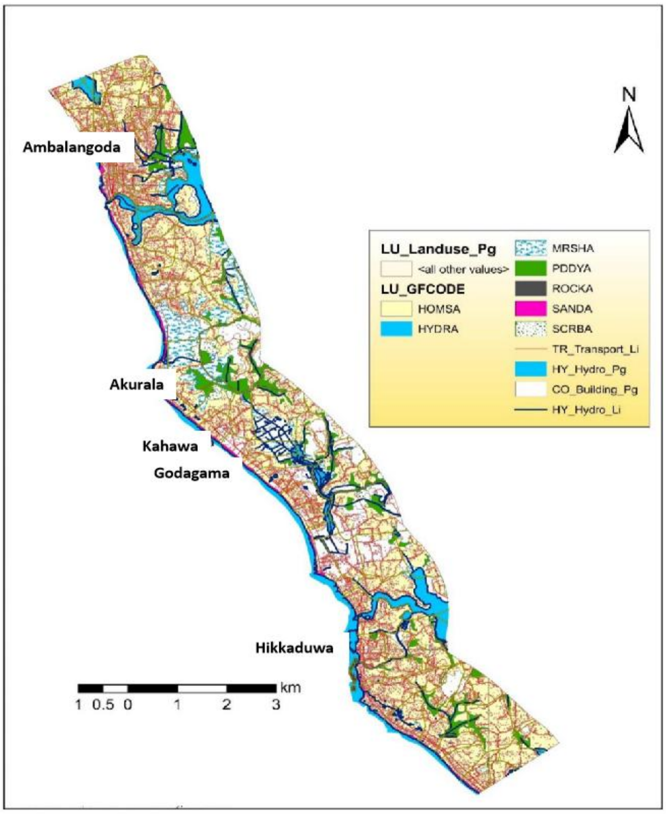


Figure 9. Spatial variation in land use in the study area.

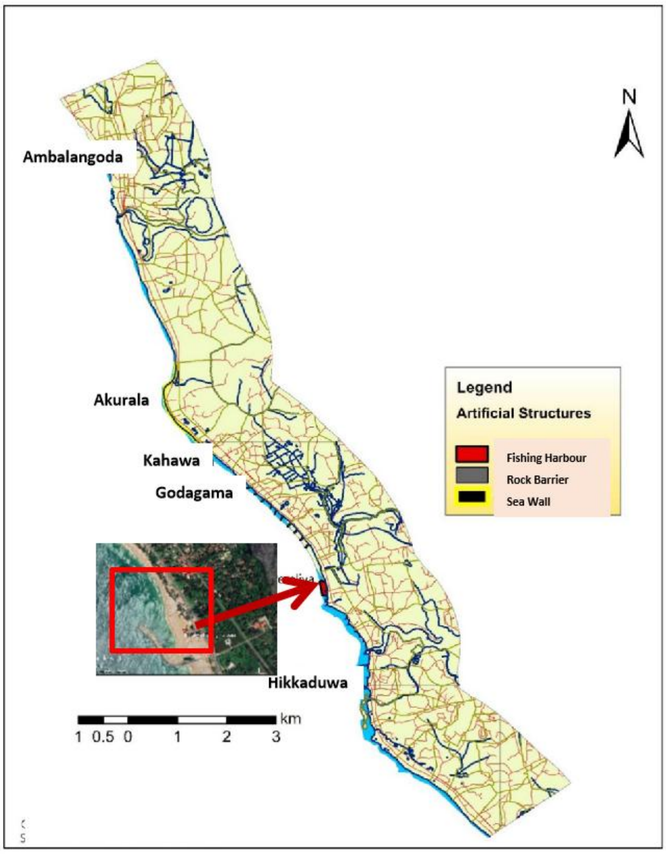


Figure 10. There are few man-made structures, and other modifications can be observed from Akurala to Hikkaduwa.

4. Discussion

Sri Lanka frequently experiences coastal flooding, particularly along the Southwest, Northeast, and Eastern coasts. However, the Southwest coast is especially prone to flooding during the active southwest monsoon seasons. This study was conducted along a section of the southwest coast, specifically from Akurala to Godagama, to identify the main factors contributing to coastal flooding in this area. The research focused on four key aspects: bathymetry, coastal geomorphology, land-use types, and human activities. Ten bathymetric profiles were analyzed within the study area to understand the near-seabed morphology. A comparison of six of these profiles revealed that previous coastal flooding incidents were closely associated with shallow bathymetry and gentle seabed slopes. For a more targeted analysis, the area was divided into three segments: Ambalangoda, Akurala, Godagama, and Godagama–Hikkaduwa.

Factors such as bathymetry, coastal morphology, land use, and human activities were examined within each segment to determine their contribution to flooding. The bathymetric analysis showed that the Ambalangoda-Akurala and Godagama-Hikkaduwa segments have steep underwater slopes, which help dissipate wave energy and thus reduce the likelihood of flooding. In contrast, the Akurala-Godagama segment has a more gradual slope (Figure 7b and 7c), which allows high-energy waves to travel further inland, increasing the risk of flooding in this section.

Digital Elevation Model (DEM) data revealed notable variations in elevation within the study area. High-elevation areas are located near Hikkaduwa and Ambalangoda, whereas the Akurala to Godagama area lies at an elevation of 0 to 3.3 meters. Many coastal flood events have recently been recorded in this low-lying area, whereas the higher elevations in the Ambalangoda to Akurala and Godagama to Hikkaduwa sections have experienced less frequent flooding. Therefore, the relatively lower elevation in the Akurala-Godagama area is a significant factor in its increased vulnerability to coastal flooding. In terms of land use, there was no notable variation across the coastal zone of the study area, indicating that land use had minimal influence on flood occurrence in the Akurala to Godagama section. Human activity was also considered in the analysis. Coastal protection structures, such as rock barriers, were constructed in all three segments. However, these structures did not appear to significantly affect the frequency or severity of flooding. Other human activities in the region, such as coral mining near Hikkaduwa and a fishing harbor in Hikkaduwa, were also analyzed. Coral mining, although present, did not have a substantial effect on flooding patterns in the Akurala–Godagama area. Similarly, the Hikkaduwa fishing harbor has a minimal influence on flood risk, as it is located at some distance from the study area.

5. Conclusions

This study aimed to identify the main physical and human factors that contribute to coastal floods, focusing on the southwest coast, particularly the stretch from the Akurala to the Godagama coastal segment. The study concludes that two key physical factors, bathymetry (underwater topography) and elevation, are primarily responsible for frequent coastal flooding in the Akurala–Godagama area. These factors contribute more significantly than human activities or land-use patterns, and are consistent across the region, but do not appear to increase flood risks. Thus, the physical landscape, particularly in the Akurala to Godagama segment, is the primary driver of frequent coastal floods on this part of the southwest coast of Sri Lanka.

Author Contributions

AW: Supervisor, Methodology, Software, Investigation, Data collection, Formal analysis, writing; **HR**: Methodology, Investigation, software, Writing.

Conflicts of Interest

There are no conflicts to declare.

References

1. Prasetya, G.S.; de Lange, W.P.; Healy, T.R. The Makassar Strait Tsunamigenic Region, Indonesia. *Nat. Hazards* **2001**, *24*, 295–307, doi:10.1023/A:1012297413280. (accessed on 27, March, 2024).
2. Moore, F.C.; Obradovich, N. Using Remarkability to Define Coastal Flooding Thresholds. *Nat. Commun.* **2020**, *11*, doi:10.1038/s41467-019-13935-3.(accessed on 22, March, 2024).
3. de Vries, H.; Breton, M.; de Mulder, T.; Krestenitis, Y.; Ozer, J.; Proctor, R.; Ruddick, K.; Salomon, J.C.; Voorrips, A.A. Comparison of 2D Storm Surge Models Applied to Three Shallow European Seas. *Environ. Softw.* **1995**, *10*, 23–42.
4. Williams, J.A.; Flather, R.A. *Interfacing the Operational Storm Surge Model to a New Mesoscale Atmospheric Model*; Nature Environment Research Council: Merseyside, England, UK, 2000.
5. Smith, D.S. and Banke, E.G., Variation of the Sea Surface Drag Coefficient with Wind Speed. *Quarterly Journal of the Royal Meteorlogical Society*, *101*, 665–673, doi:10.1002/qj.49710142920. (accessed on 10, March, 2024).
6. Wijayawardane, I.; Ansaf, K.; Ratnasooriya, A.; Samarawickrama, S. Coastal Erosion: Investigations in the Southwest Coast of Sri Lanka. In Proceedings of the International Conference on Sustainable Built Environment (ICSBE-2010), Kandy, Sri Lanka, 2013.
7. Weather and Climate, Southern Sri Lanka Climate, https://weatherandclimate.com/sri-lanka/southern-sri-lanka (accessed on 18, March, 2024).
8. Hikkaduwa Divisional Secretariat office,Ministry of Home Affairs, http://www.hikkaduwa.ds.gov.lk/index.php/en/statistical-information.html. (accessed on 14, March 2024).
9. Wolf, J. Coastal Flooding: Impacts of Coupled Wave-Surge-Tide Models. *Nat. Hazards* **2009**, *49*, 241–260.
10. Athulathmudali, S.; Balasuriya, A.; Fernando, K. *An Exploratory Study on Adapting to Climate Change in Coastal Areas of Sri Lanka*; Mudrana Printers: Colombo, Sri Lanka, 2011; ISBN 9789551040581.
11. Grases, A.; Gracia, V.; García-León, M.; Lin-Ye, J.; Joan Sierra, J.P. Coastal Flooding and Erosion under a Changing Climate: Implications at A Low-Lying Coast (Ebro Delta). *Water* **2020**, *12*, doi:10.3390/w12020346..(accessed on 08, February, 2024).
12. Smith, M.W.; Vericat, D. Evaluating Shallow-Water Bathymetry from Through-Water Terrestrial Laser Scanning under A Range of Hydraulic and Physical Water Quality Conditions. *River Research and Applications* **2014**, *30*, doi:10.1002/rra.2687. (accessed on 08, February, 2024).
13. Arnott, R.D. *An Introduction to Coastal Processes and Geomorphology*; Cambridge University Press: Cambridge, England, UK, 2010.
14. Sugianto, S.; Deli, A.; Miswar, E.; Rusdi, M.; Irham, M. The Effect of Land Use and Land Cover Changes on Flood Occurrence in Teunom Watershed, Aceh Jaya. *Land* **2022**, *11*, doi:10.3390/land11081271.(accessed on 23, March, 2024).
15. Wasana S.G.S.; Thennakoon T.M.S.P.K. Impact of Anthropogenic Activities on Coastal Landscape Changes in Unawatuna Coastal Zone, Sri Lanka. *IJMS* **2018**, *5*, 139–154.