advances in Technology

Adv. Technol. 2024, 5(1), 1-10

Full Paper

Headland Bay Beaches and Zeta-Form Beaches as Geo Resources: Morphological Evidence from Sri Lanka

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Received: 16 May 2023; Revised: 06 August 2024; Accepted: 08 August 2024; Published: 16 March 2025

Abstract

The term "geo-resources" refers to all geological resources that serve as the basis for life in modern-day society. The beach systems associated with the southwestern and southern coastal zones are well rich in headland bay beaches and zeta-form beaches of different sizes. Among those beaches, beaches are also a significant feature in the selected area from Maggona Head (southwestern coast) to Rekawa Lagoon (southeastern coast). The evolution of these beaches depends on wave forcing and morphological characteristics, and the morphological feature is defined as a beach lying on the leeward side of a headland subjected predominantly to wave attack. These beaches characteristically have a seaward-concave plan shape resulting from erosion caused by refraction, diffraction, and reflection of waves into the shadow zone behind the headland. Tide-induced currents have no direct effect on the plan shape of headland-bay beaches in the area. Various physical changes were observed in the study areas via Google Earth Pro, and historical imagery was used to understand the changes. MepBay software was used to evaluate the stability of the beaches. Aerial images of the bayed beaches were opened via MepBay software, and the following control points were defined manually. According to the findings, the coastline and coastal zone have changed drastically over the years. Coastal infrastructure development and accretion/erosion caused by monsoon wind patterns are the main influences on such changes, and many embayed beaches in the study area are in static equilibrium, but few are in a dynamic equilibrium state. Most beaches are either used for fisheries or for tourism activities. However, since many beaches have the potential to be used as renewable energy sources and biodiversity hotspots, the present study suggests incorporating as many uses as possible into these resources rather than utilizing them for a single purpose. However, proper scientific studies should be conducted prior to commencing such activities to ensure long-term sustainability.

Keywords: equilibrium, geo resources, headland bay beaches, southwestern and southern coasts, zeta-form beaches.

Introduction

Georesources are natural resources that come from the Earth's surface, subsurface, or oceans. These resources include minerals, fossil fuels, water, soil, and timber, among others. The term "georesources" encompasses all resources (except for solar energy) that serve as a foundation for the life of modern human society and whose comprehensive use involves human intervention with the system Earth [1]. Georesources or geological resources are elements in a liquid, solid or gaseous state that are susceptible to exploitation on or within the Earth's crust, depending on their concentration (e.g., industrial rocks or metallic or nonmetallic minerals). They also include nonrenewable elements of the earth that are valuable for the science, economy and education of humans [2]. In addition to tangible materials, ecosystem services and social and economic benefits associated with various geological locations (e.g., beaches, forests, and marsh environments) are also considered important outcomes of geo-resources. Georesources comprise spaces of relevant geological value with the potential to be used and managed as a resource. Therefore, georesources are an essential development factor worldwide, as they are oriented toward rational use to improve the quality of life of the surrounding population. These resources are important for developing countries because they provide the raw materials necessary for industrialization and economic development. For example, minerals such as iron, copper, and aluminum are used in the production of infrastructure and manufacturing equipment. Fossil fuels such as oil, coal, and natural gas provide energy for transportation and electricity generation. Water is essential for agriculture and human consumption, whereas timber is used for construction and furniture production. Developing countries often have abundant geo-resources, but they may lack the technology, infrastructure, and expertise to extract and process them efficiently. This can result in missed economic opportunities and limited access to critical resources. By developing their geo-resources, developing countries can increase their economic growth, create jobs, and improve their standard of living. However, it is important to balance the exploitation of these resources with environmental sustainability and social responsibility to avoid negative impacts on communities and ecosystems [3, 4].

Headland bay beaches and zeta beaches are two different types of coastal formations that could be utilized as valuable georesources if used properly. By definition, Headland bay beaches are beaches characterized by their location on a stretch of coastline that juts out into the ocean, creating a bay-like shape (Figure 1). Headlands or promontories often provide shelter from wind and waves, resulting in calmer waters than other nearby beaches do. Headland bay beaches can also be more exposed to swells and currents, making them popular for surfing. Depending on the stability of the beach, these bays are divided into static or dynamic equilibrium [5-7].

Figure 1. Weligama headland bay

Zeta beaches: Zeta beaches are designed to mimic the natural shape and function of a beach, but they are constructed using a series of interconnected structures that help reduce the impact of waves and currents (Figure 2). These structures are typically made of sand-filled geotextile bags, concrete, or other materials. The shapes of the structures, which are arranged in a series of interconnected "Z" shapes, help reduce the energy of incoming waves and create a calm zone on the landward side. Zeta beaches can be used for coastal protection, recreational and environmental purposes [8, 9].

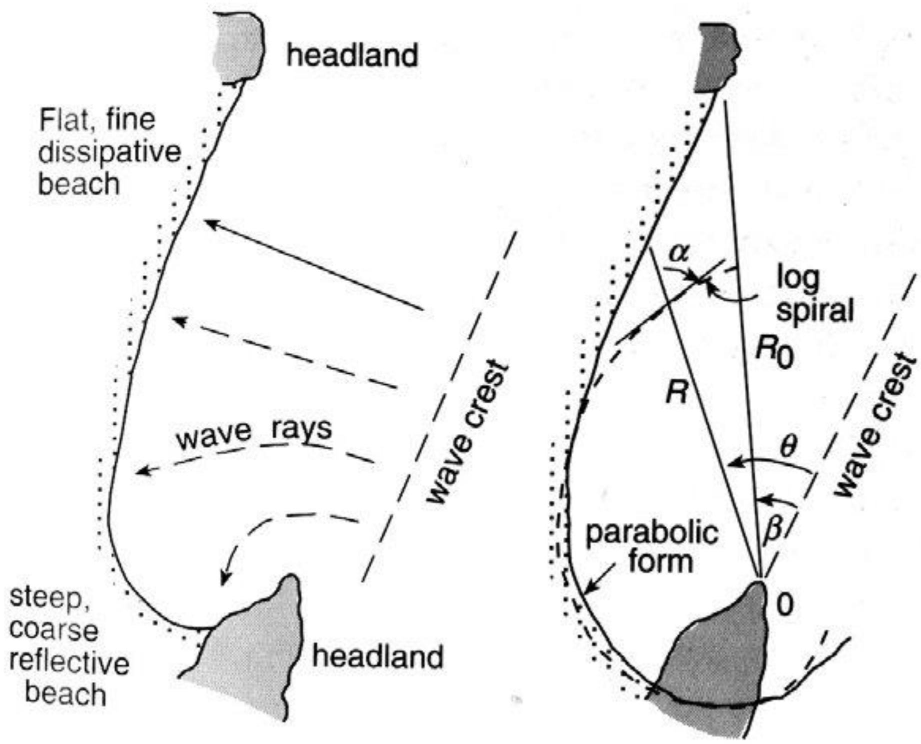

Figure 2. Diagram of a "Zeta-form" beach planform [10].

The beach systems associated with the southwestern and southern coastal zones in Sri Lanka are rich in headland bay beaches and zeta-form beaches of different sizes [11]. Among those beaches, beaches are also a salient feature in the selected area. The evolution of each beach system depends on wave forcing and morphological characteristics, and the most commonly observed dynamic is that of beach rotation due to the prevailing wave direction [12]. These beaches can be recognized as geo-resources composed of a mix of boulders, pebbles, sand and mud and therefore have the attributes of a combination of shoreline types. If managed properly, such geo-resources could be important in the development process of the country [13]. Understanding the unique characteristics and stability of these beaches is detrimental to managing and conserving these resources.

Therefore, this study presents beach profiles for headlands and bay coasts, pocket beaches and zeta-form beaches. On the basis of the stability of the beach systems. Current and potential uses of beaches were identified for future studies.

Materials and Methods

Study Location

This study was based on beaches from Maggona to Rekawa, Sri Lanka. Along this coast, highly utilizable but neglected beaches were selected from field observations and satellite images.

MepBay Analysis

Physical changes in geographic resources were observed in the study area via Google Earth Pro, and historical imagery was used to understand the degree of changes in the study area. Since many interest points in the study area included beaches, the stability of the beaches was assessed via MepBay 3.0 software. MepBay is an open-source software that uses a parabolic shape model to evaluate the stability of beaches. Using MepBay, the parabolic model can be easily applied to any of the beaches by providing 03 manual inputs, and compared with other available software, this model is user friendly and easy to operate. Additionally, it can be used to determine the optimum designs from the number of different options [7].

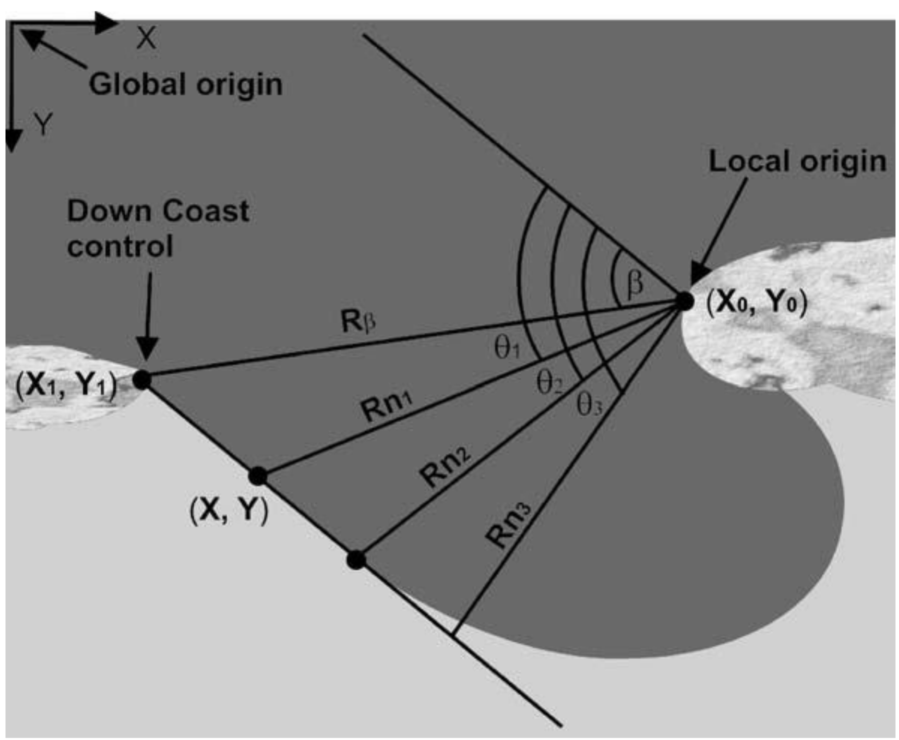

Figure 3. Definition sketch for the parabolic bay shape model [14].

Aerial images of bay beaches were opened via MepBay software, and the following control points were defined manually: (a) up coastal diffraction point, (b) down coastal control point, and (c) down coastal tangent point (Figure 3). This analysis was used to identify the stability of each embayed beach. The Maggona complex, Dodanduwa, Balapitiya, Ahungalla and the coastal stretch spreading between Dickwella and Tangalle were selected as study sites because of their importance in various aspects.

Current and Potential Utilizations

After the bay categories and the stability of each bay were understood, the current uses of the study locations were identified through field observations. Finally, the stabilities and natures of the beach potential uses were identified and discussed.

Results and Discussion

The study areas have experienced considerable overall changes in coastal areas during the last 30 years. Accretion and erosion could be observed throughout the study area from 2015 to the present day. Figure 4 shows the Maggona beach complex (6°30'20.86"N, 79°58'35.84"E). Bayed beach (B) in Maggona head is currently used as a fishery harbor. As observed in section B, two natural headlands act as wave diffraction points, and very few morphological changes have occurred on this beach over the last 30 years.

Figure 4. Maggona complex

South of the Maggona complex, Beruwala Harbor (6°28'20.72"N, 79°58'43.30"E) is built on a natural headland beach. However, artificial breakwater wave action has been minimized, and calm water, which is suitable for boat landings, has been created. In the Dodanduwa Complex, 03 embayed beaches can be observed, as shown in Figure 5. Section A is used as a fish landing site because it minimally changes its southern headland by creating a breakwater by adding rocks. Additionally, the Rathgama Lake mouth is connected to this section. Section B is also used to land fish boats, even though it is not up to the extent of section A. Since Dodanduwa cliffs and surrounding recreational areas (e.g., for diving and snorkeling) attract tourists, few water sports centers and hotels are available. However, the observations of the study areas demonstrate that the area is underutilized in this aspect. Therefore, tourism activities should be diversified at the site while maintaining the current utilization of the Dodanduwa complex.

The Ahungalla complex (6°19'2.59"N, 80° 1'45.34"E) has conditions similar to those of the Dodanduwa complex, such as sea cliffs, which act as headlands. Owing to the aesthetic nature of the area, there are many tourist hotels in the area.

Figure 5. Embayed beaches in the Dodanduwa complex.

Figure 6 comprises Zetaform Beach in section A and pocket beaches. A pocket beach is a scale beach that is isolated between two headlands and, on the basis of its location and size, can be utilized for many uses.

Figure 6. The beach area from Mawella headland to Rekawa Lagoon comprises headlands, Zetaform beaches and pocket beaches.

Table 1 summarizes the results of the MepBay analysis of the selected study sites. When the coastal zone from Dickwella to Tangalle is considered, these areas are highly vulnerable to external forces and rapid changes. Therefore, frequently monitoring these sites and making necessary arrangements for area protection are recommended.

Table 1. Stability and importance of each location along the southwestern and southern coasts

Study Site	Stability
Maggona	Static equilibrium
Dodanduwa	Static equilibrium
Balapitiya	Static equilibrium
Ahungalla	Static equilibrium
Dickwella to Tangalle	Most embayed beaches are in dynamic equilibrium

As beaches in Dickwella to Tangalle are mostly in dynamic equilibrium, their stability could be saturated if artificial breakwaters or groynes are constructed. As discussed earlier, breakwaters could be used to create calm waters where groynes could be used to stabilize beaches. Headland bay beaches and zeta beaches are two different types of beach formations that have different characteristics and potential uses. According to observations and a literature review, the major uses as summarized below [15-17].

Considering headland bay beaches:

- Surfing: Headland bay beaches are often characterized by strong waves, which make them ideal for surfing (e.g., Benthota).
- Fishing: These beaches are also great areas for fishing, as water currents and underwater formations create ideal habitats for fish (e.g., the Dodanduwa complex).
- Tourism: Many headland bay beaches are located in areas with scenic views and natural beauty, making them popular tourist destinations (e.g., Ahungalla, Benthota).

Zeta Form Beaches:

- Coastal Protection: Zeta beaches are often designed as a form of coastal protection, as their unique shape and design can help reduce the impact of coastal erosion and storm surges. They can also be used to prevent or mitigate the effects of coastal flooding.
- Recreation: Zeta beaches can also be used for recreational purposes, such as swimming and sunbathing, especially in areas where there are few natural beaches.
- Environmental Protection: These types of beaches can be designed to incorporate features that support local ecosystems, such as sand dunes, salt marshes, and wetlands. This can help protect and preserve biodiversity in the area.

Importantly, the uses and potential uses of both headland bay beaches and zeta beaches depend on a variety of factors, such as their location, accessibility, and environmental conditions. As such, the selected locations currently have the following uses (Table 2).

Table 2. Present uses of the study locations

Study Site	Importance
Maggona	Fishery harbors
Dodanduwa	Fish landing sites and tourism
Balapitiya	Tourism
Ahungalla	Tourism
Dickwella to Tangalle	Fish landing sites, tourism, important ecological environments etc.

Notably, most of these study locations currently have one or two current uses, but they could be used much more. Therefore, understanding beach stability, morphological characteristics, and other factors of georesource utilization could be efficiently accomplished in a combined manner. While the findings of the present study on beach stability could be used to identify future development plants, comprehensive scientific studies should be conducted on other aspects of coastal geo-resources to accurately assign the correct uses for each beach system. However, the present study identified the potential sustainable uses of beach resources as follows.

The sustainable use of beach resources involves the utilization of these resources in a way that does not cause long-term harm to the environment or the local community. There are several approaches to sustainable beach resource utilization [13, 18, 19].

1. Responsible tourism: Tourists can have a significant effect on the natural environment and the local community. Sustainable tourism practices can help minimize negative impacts on the environment, such as by reducing waste, conserving water, and respecting local cultures. Tourists can also support local businesses that prioritize sustainable practices. For this reason, the diversification of tourism activities and ecotourism could be promoted in many locations. For example, the Ahungalla complex is a popular tourist destination that could be used to promote different tourism activities, such as educational tourism and marine tourism.

2. Protection of natural habitats: Beaches are often important habitats for a variety of plant and animal species. Protecting these habitats, such as through the establishment of marine protected areas or the use of environmentally friendly beach infrastructure, can help preserve the natural environment and promote biodiversity. Many of the sites discussed in this study are rich in biodiversity. However, some of the present practices do not ensure the conservation of these sensitive ecosystems. However, through the application of diverse tourism activities such as ecotourism and the sustainable application of fisheries and resource utilization, many sensitive sites could be protected. (e.g., Benthota and Dodanduwa areas)

3. Sustainable fishing practices: Many coastal communities rely on fishing for their livelihoods. Adopting sustainable fishing practices, such as avoiding overfishing, using fishing gear that minimizes bycatch, and implementing fishing regulations that protect vulnerable species, can help ensure that fishing remains a viable source of income for the local community.

4. Renewable energy: Beaches are often sunny and windy, making them ideal locations for the installation of renewable energy infrastructures such as solar panels and wind turbines. This can reduce reliance on fossil fuels and decrease the environmental impact of energy production. For example, some of the Zetaform beaches in the study area could be used for this purpose. However, further studies are needed to ensure its suitability and environmental impacts before such development projects are commenced.

The above are just a few examples of sustainable approaches to beach resource utilization. The key is to prioritize the long-term health of the environment and the local community rather than short-term gains.

Conclusion

In this research, coastal zone alterations and the stability of the embayed beach along the coastline from Maggona to Tangalle were established via Google Earth images and MepBay software. The present research indicates that the coastal zone and coastline have undergone significant changes over time. The main factors causing these changes are the construction of coastal infrastructure and accretion/erosion caused by monsoon wind patterns. Few beaches in the study region are in dynamic equilibrium, while many beaches are in static equilibrium. Even though these beaches are utilized to some extent, as a developing country, such resources should be utilized in a collective way rather than for single use. Such approaches are much needed under the present conditions, as geo-resources are finite and highly vulnerable. Therefore, these geo-resources should be utilized more efficiently in a sustainable manner. The Department of Fisheries and Aquatic Resources, Sri Lanka Coastal Guard, Coast Conservation and Coastal Resources Management Department, and all other coastal engineering activities should find value in the study's findings.

Conflicts of interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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