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Geoenvironmental analysis applied to the study of vulnerability to erosion on the Bispo beach/Mosqueiro-PA.

Análise Geoambiental aplicado ao estudo da vulnerabilidade à erosão na praia do Bispo/Mosqueiro-PA.

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Abstract: Erosion is a complex phenomenon as it involves the direct or indirect action of several factors, such as geological and geomorphological characteristics, soil types, climate, vegetation, and human interference, which modifies the natural conditions of these elements. This study aims to generate a vulnerability map of erosion at Bispo Beach, in Mosqueiro/PA, through the intersection of geoenvironmental variables: geomorphology, geology, soil, vegetation, land use, and climate. Data from IBGE, INPE, and EMBRAPA were used, processed, georeferenced, and standardized. The results indicate two distinct scenarios: urban area and forest. The identification of erosion points allowed for an analysis of the dynamics of these processes and their impacts on the biophysical environment. Thus, the intersection of geoenvironmental variables related to coastal erosion enabled the characterization of these elements and provided essential information for identifying the most vulnerable areas, considering that climatic factors and tidal effects act directly in the coastal region.

Keywords: Vulnerability; Anthropogenic changes; Geoenvironmental Analysis.

Resumo: A erosão é um fenômeno complexo, pois envolve a ação direta ou indireta de diversos fatores, tais como características geológicas e geomorfológicas, tipos de solos, clima, vegetação, além da interferência humana, que modifica as condições naturais desses elementos. Este estudo tem como objetivo gerar um mapa de vulnerabilidade à erosão da Praia do Bispo, em Mosqueiro/PA, por meio do cruzamento de variáveis geoambientais: geomorfologia, geologia, solo, vegetação, uso do solo e clima. Foram utilizados dados do IBGE, INPE e EMBRAPA, tratados, georreferenciados e padronizados. Os resultados apontam dois cenários distintos: área urbana e floresta. A identificação dos pontos de erosão permitiu analisar a dinâmica desses processos e os impactos no meio biofísico. Dessa forma, o cruzamento das variáveis geoambientais relacionadas à erosão costeira possibilitou a caracterização desses elementos e forneceu informações fundamentais para a identificação de áreas mais vulneráveis, considerando que fatores climáticos e efeitos de maré atuam diretamente na região costeira.

Palavras-chave: Vulnerabilidade; Mudanças Antrópicas; Análise Geoambiental.

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1. Introduction

Erosion is a highly complex phenomenon since it involves the direct or indirect action of various factors, such as geological and geomorphological characteristics, soil types, climate, vegetation, and human interference, which modify the natural conditions of each of these factors (Oliveira et al., 2018; Camões & Uacane, 2020). Coastal vulnerability, on the other hand, relates its susceptibility to data concerning exposure, coping capacity, and physical and social systems. It is often viewed as an intrinsic characteristic of a system or element, constantly expanding and encompassing the coastal environment's ability to adapt to anthropogenic changes (Birkmann, 2007; Menezes et al.; 2018).

Geoindicators are widely used in the analysis of coastal erosion vulnerability and can be applied through a set of observations considering both qualitative and quantitative parameters (Martins & Pereira, 2014). These indicators also assist in modeling to identify and classify the intensity level (from low to high) using thematic maps across an area, as seen in Menezes et al. (2018) and Vale et al. (2021).

Geoindicators are used to understand scenarios and can be applied to provide environmental monitoring actions at scales corresponding to the study's needs. They are integrated into databases that incorporate sophisticated techniques to assess geographic information for environmental purposes, serving as cost-effective alternatives for integrated coastal management in the public context (Bush et al., 1999; Menezes et al., 2018).

The present article, titled *Geoprocessing Applied to the Study of Erosion Vulnerability at Bispo Beach, Mosqueiro Island, Pará State*, aims to analyze the factors driving local coastal erosion processes, focusing on the reality of local conditions. Thus, the approach considers the physical characteristics of the study area and land use patterns as the basis for analyzing the related processes.

Geoenvironmental characteristics represent the natural elements that make up the physical environment, such as geology, geomorphology, pedology, and climatic aspects, among others, which form the basis for understanding the structuring and organization of physical space. In this context, the spatialization of this information for the general characterization of areas can be achieved using various technologies, including geoprocessing. The technique that employs Geographic Information Systems has been widely disseminated as a practical and effective tool, providing the necessary technical foundations for better management (Silva Filho et al., 2021).

In this sense, it becomes possible to cross-reference geoenvironmental variables related to coastal erosion to characterize these variables and obtain information that can serve as a basis for comparing and identifying areas with a higher potential for vulnerability. This ensures the necessary prior knowledge for the implementation of management and planning strategies..

In light of this, this study aimed to analyze the erosion processes at Bispo Beach in Mosqueiro, Pará, based on the cross-referencing of geoenvironmental variables—geomorphology, geology, soil, vegetation, land use, and climate—to assess their influence on this region.

2. Methodology

2.1 Characterization of the study area

Located in the northern region of Brazil, the study area is situated on Mosqueiro Island, in the metropolitan region of Belém, Pará, between the coordinates 1°08' to 1°09' south latitude and 48°27' to 48°28' west longitude (Figure 1).

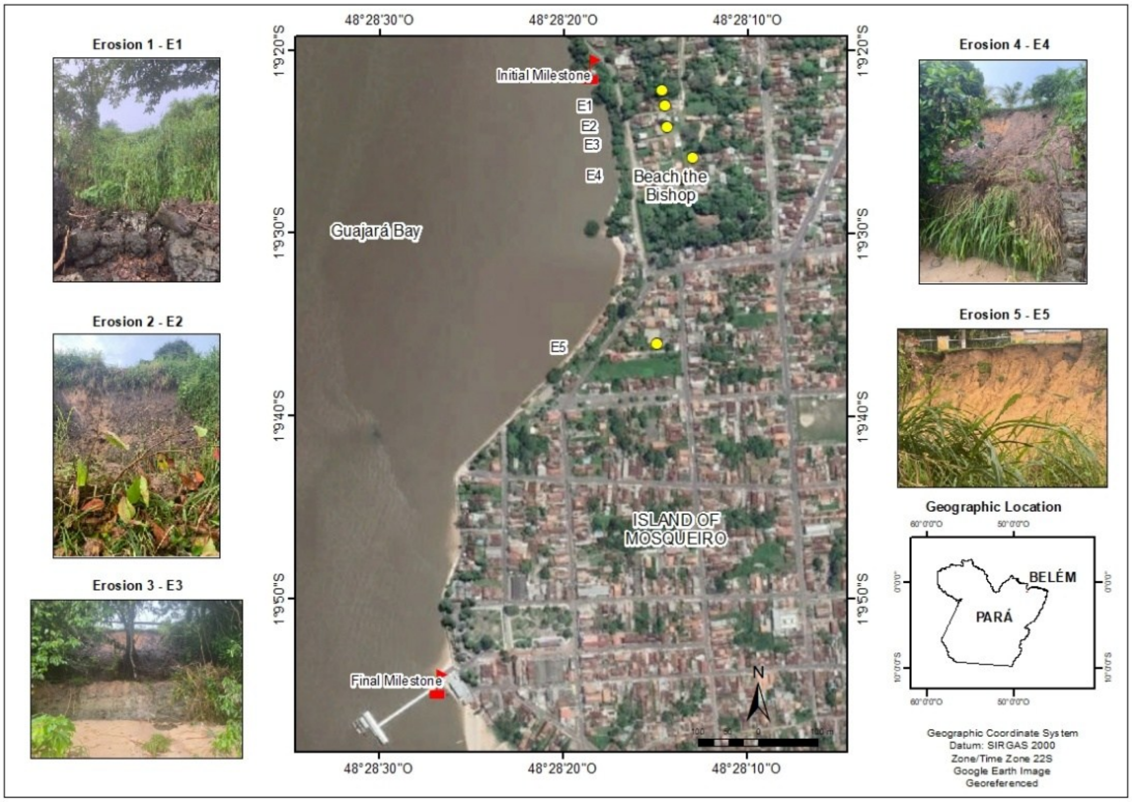

Figure 1 – Location of the study area on Mosqueiro Island, Belém, Pará.
Source: Authors (2023).

2.2 Climate of the region

The climate of the region where Bispo Beach is located, in Mosqueiro, Pará, is classified by Köppen as Af-type, characterized by an average annual temperature of 25°C, with a minimum of 21.9°C and a maximum of 31.4°C. The relative humidity is approximately 84%, with an average annual precipitation of 2,900 mm.

Rainfall in Mosqueiro occurs in two distinct periods: one from December to May (rainier season) with higher rainfall intensity and another from June to November (drier season) with lower rainfall intensity. Throughout the year, this variation in precipitation can influence the sedimentary and morphological dynamics of the beaches, resulting in a constant seasonal interaction between agents (tides, waves, winds, rainfall, and anthropogenic action) and the processes acting upon them (erosion, transport, and sedimentation) (Viana, 2013; Braga, 2019).

For the climate analysis, data provided by INMET (National Institute of Meteorology) from the years 2019 and 2021 were used. Annual air temperature and precipitation data from the Belém meteorological station, located near Bispo Beach, were collected.

2.3 Geology

On Mosqueiro Island, the geology of the study area was identified using data provided by the Brazilian Institute of Geography and Statistics (IBGE) through the Geosciences portal. Geological characteristics of this area were determined, revealing the presence of Neo-Pleistocene detrital-lateritic cover and a water body (Figure 2).

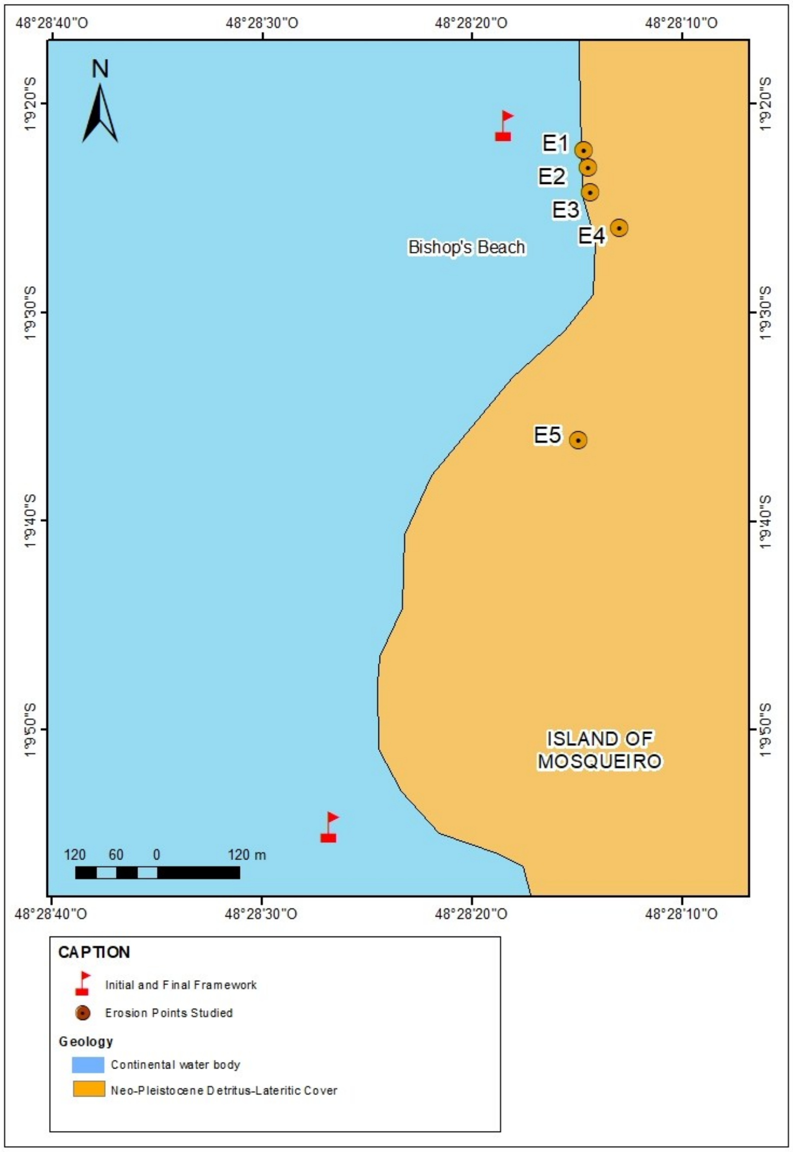

Figure 2 – Geological Map of Bispo Beach, Mosqueiro, Pará.
Source: Authors (2023).

However, according to studies by Igreja et al. (1990), Rossetti (2001), and Neve et al. (2019), different characteristics were highlighted compared to those identified in the study area, particularly in the northwest. These authors described the coastal geometry as being strongly influenced by geological fault systems, giving it an irregular, rugged, and angular appearance, with the presence of active cliffs sculpted in sediments of the Barreiras/Post-Barreiras Group (sandstones, claystones, siltstones, conglomerates), surrounded by embayed beaches, which are bounded at their extremities by promontories.

On the other hand, the alluvial plain and beaches develop in areas depressed by neotectonic activity and are therefore subject to tidal flooding and recent Holocene depositional processes (El-Robrini, 2001; Viana, 2013; Neve et al., 2019).

2.4 Geomorphology

Geological data provided by the Brazilian Institute of Geography and Statistics (IBGE, 2023) through the Geosciences portal were used to characterize the geomorphology of Bispo Beach, in Mosqueiro, Pará. The area was identified as consisting of Mangrove and Ria Coastal Areas and Quaternary Sedimentary Deposits, distributed along the coastal zone or inland (Figure 3).

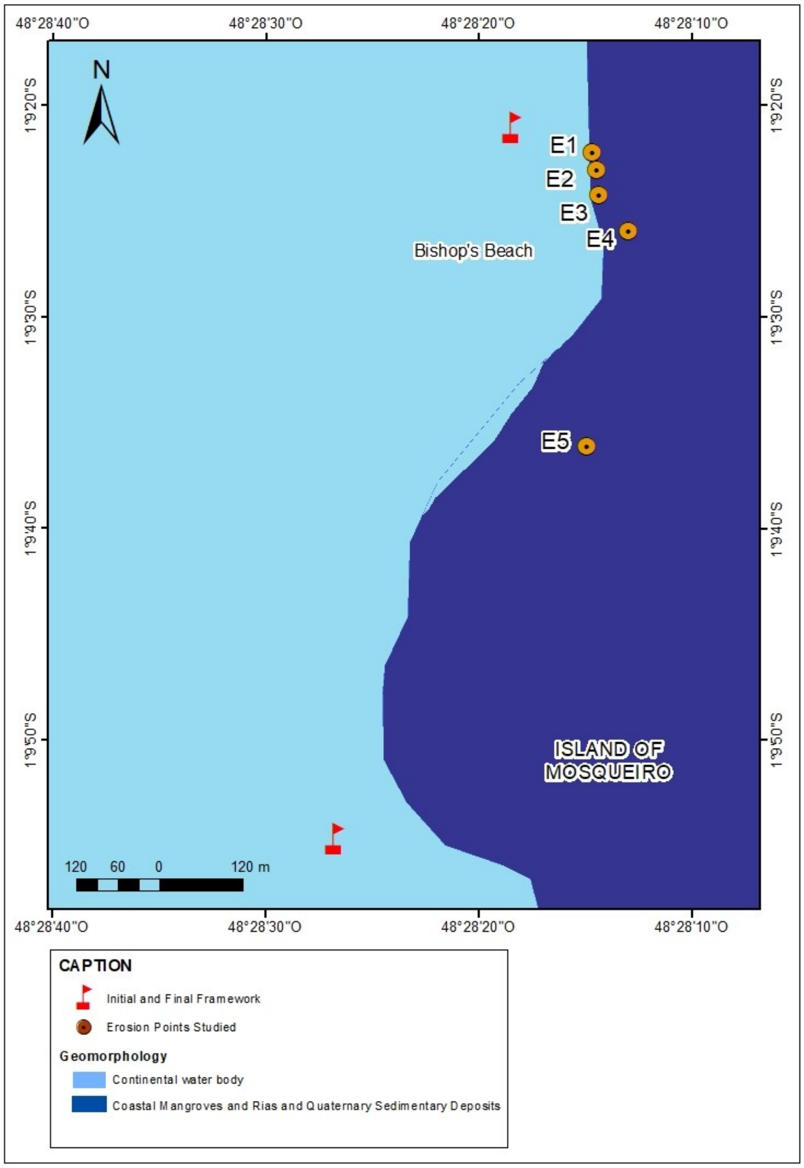

Figure 3 – Geomorphological Map of Bispo Beach, Mosqueiro, Pará.
Source: Authors (2023).

2.5 Use and use and occupation of land

In the Praia do Bispo watershed area, in Mosqueiro/PA, three types of land use and land cover are identified: Forest, Urban Area, and Exposed Soil. According to BRAGA (2019), the remaining patches of primary vegetation are classified as Tropical Evergreen Forest. The areas that were cleared for civil construction and urban infrastructure (such as piped water, waste collection, electricity, sewage systems via sewer or stormwater networks, asphalt, sidewalks, etc.) were replaced by secondary vegetation known as capoeira.

The Terraclass project, a partnership between the National Institute for Space Research – Amazon Regional Center (INPE/CRA), Embrapa Eastern Amazon (CPATU), both located in Belém - PA, and Embrapa Agricultural Informatics (CNPTIA), based in Campinas – SP, provides land use and land cover mapping of the Brazilian Legal Amazon. These data were used to create the land use and land cover map of Praia do Bispo, in Mosqueiro/PA (Figure 4).

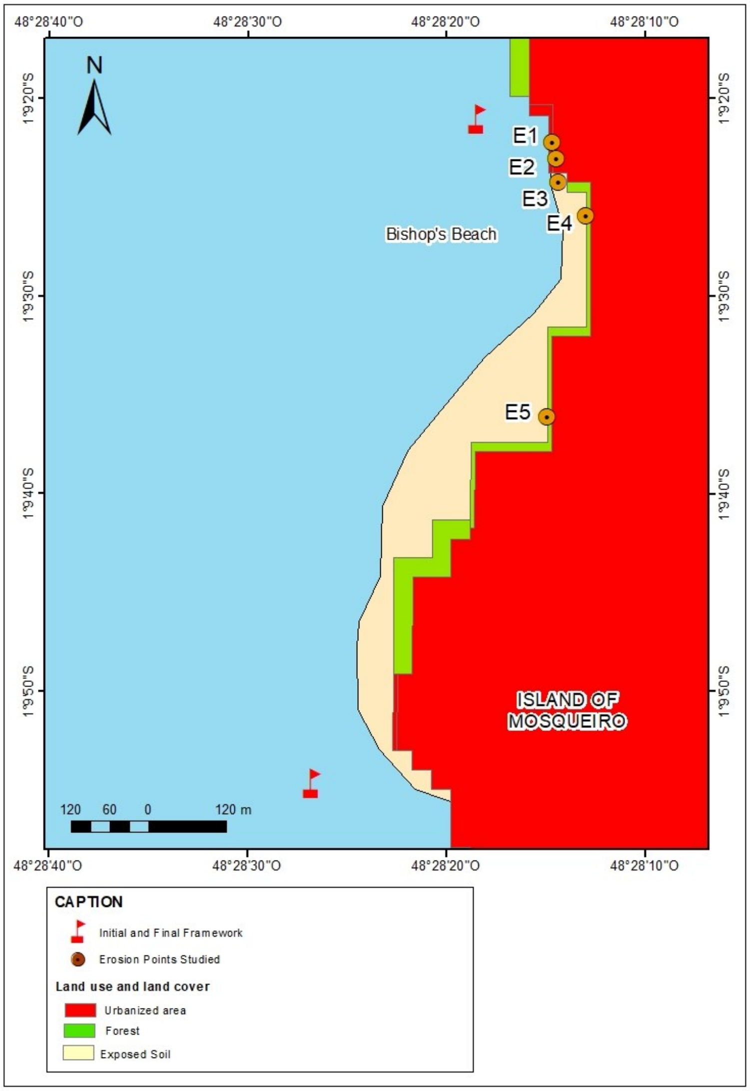

Figure 4 – Land Use and Land Cover Map of Praia do Bispo, Mosqueiro/PA.
Source: Authors (2023).

2.6 Pedology

Based on data provided by IBGE, a pedology map of the study area was generated. Two types of soil were identified in the area, with Dystrophic Yellow Latosol being identified (Figure 5).

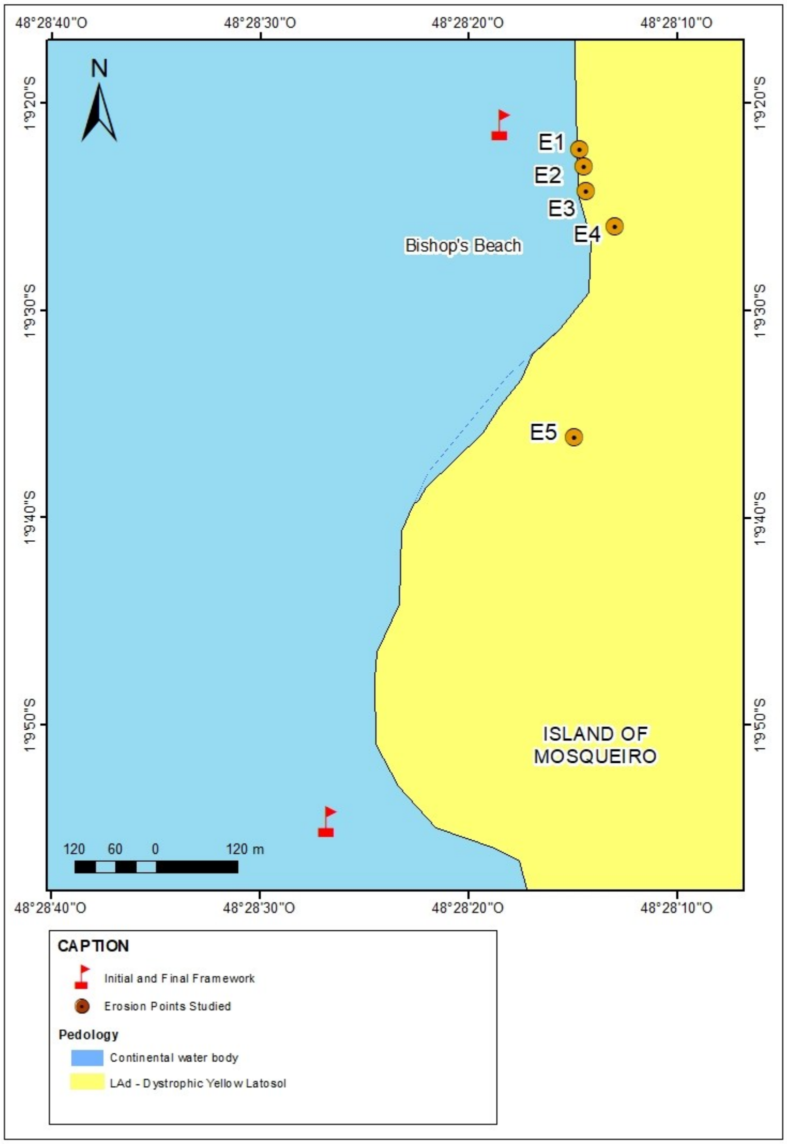

Figure 5 – Pedological Map of Praia do Bispo, Mosqueiro/PA.
Source: Authors (2023).

2.7 Slope

The relief of the region is characterized by the predominance of flat or gently undulating terrain, explaining the low slope observed in the area. The slope value is defined by the variation between two points on the terrain and the horizontal distance between them. An DEM generated from the SRTM image of the study area was used, applying the Slope tool in ArcGIS 10.5 software. It was observed that most of the terrain in Praia do Bispo, in Mosqueiro/PA, is indeed flat, with gently undulating relief in only a few areas (Figure 6).

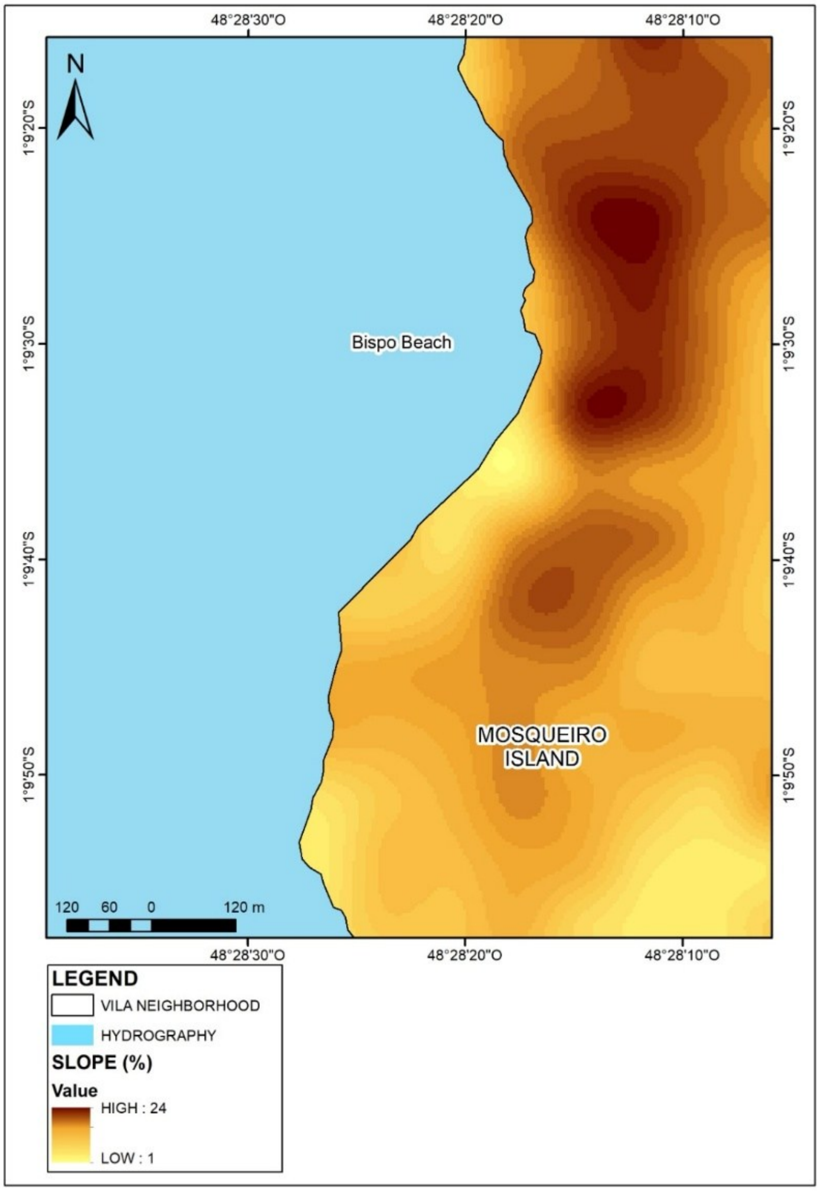

Figure 6 – Slope Map of Praia do Bispo, Mosqueiro/PA.
Source: Authors (2023).

3. Methodology

To structure the georeferenced database containing information on climate, geology, geomorphology, pedology, land use and land cover, hydrology, and slope of Praia do Bispo, in Mosqueiro/PA, a survey of existing information was conducted using data from IBGE, INPE, and EMBRAPA. These institutions provide free Shapefiles (Vectors) for the state of Pará. The data were processed, georeferenced, and standardized with a spatial resolution of 5 m, at a scale of 1:120,000, using the UTM (Universal Transverse Mercator) cartographic projection system and the SIRGAS 2000 Datum. The geographic information system used to process the data was ArcGis 10.5 software, which is capable of supporting a large volume of information, integrating vector data (maps), matrix or "raster" data (usually satellite images or photos) and tabular data (tables) into a single structure.

With all the maps in hand, specific erosion points were selected along Praia do Bispo (E1, E2, E3, E4, and E5) to analyze the intersection of information. The use of land use and land cover data is of fundamental importance since anthropogenic actions form the basis for geoenvironmental analyses of the region. This approach helps identify issues and develop strategies that can positively impact the area in question. These combinations help identify the vulnerabilities and potentials within the study area. Additionally, it is a valuable tool for defining and monitoring land use in the region in a technically appropriate manner while respecting areas with different environmental suitability (Figure 7).

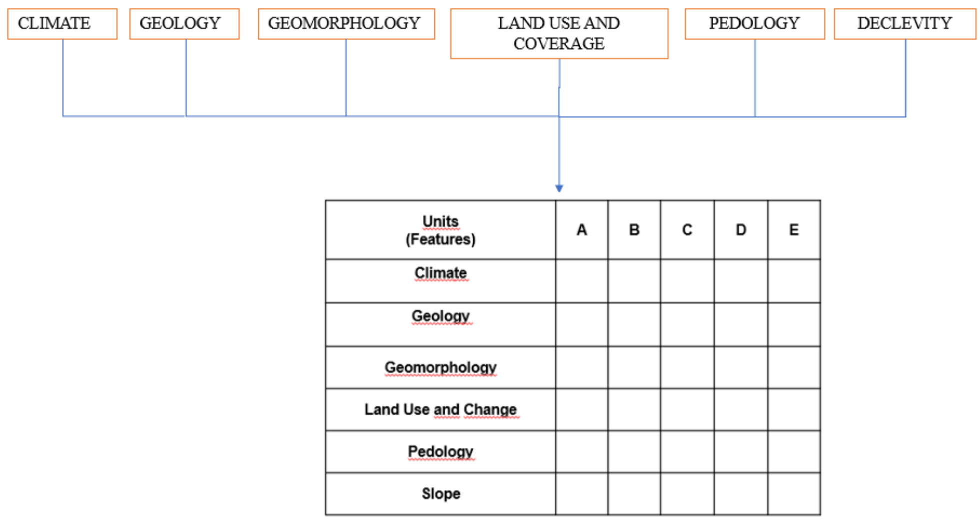

Figure 7 – Illustration of Map Overlays for the Development of the Geoenvironmental Map.
Source: Authors (2023).

3. Results and discussion

From the overlay of thematic information related to Praia do Bispo, Mosqueiro Island, the necessary elements were used to define the resulting scenarios for land use and land cover, pedology, geology, and geomorphology. As a result, two types of scenarios were identified for areas occupied by Forest and Urban Area (Table 1).

Table 1 – Overlay of Geoenvironmental Parameters and Identified Scenarios.

Uses	Scenarios
Forest	F. LAD. PC. CDLNP.
Urban Area	AU. LAD. PC. CDLNP

Source: Authors (2023).

In the scenario F. LAD. PC. CDLNP, the areas were characterized as Forest (F), with pedological features of Dystrophic Yellow Latosol (LAD), geomorphological features of Coastal Plain (PC), and geological characteristics of Neo-Pleistocene Detrital-Lateritic Cover (CDLNP).

Meanwhile, in the scenario AU. LAD. PC. CDLNP, the areas were identified as Urban Areas (AU), with pedological features of Dystrophic Yellow Latosol (LAD), geomorphological features of Coastal Plain (PC), and geological characteristics of Neo-Pleistocene Detrital-Lateritic Cover (CDLNP). After overlaying the geoenvironmental parameters of Praia do Bispo on Mosqueiro Island, analyses were conducted on the identified erosion points, incorporating hydrological, slope, and climate analyses of the region to generate a geoenvironmental characterization of these points. The points E1, E2, E3, E4, and E5, which will be analyzed, are also shown in Figure 8.

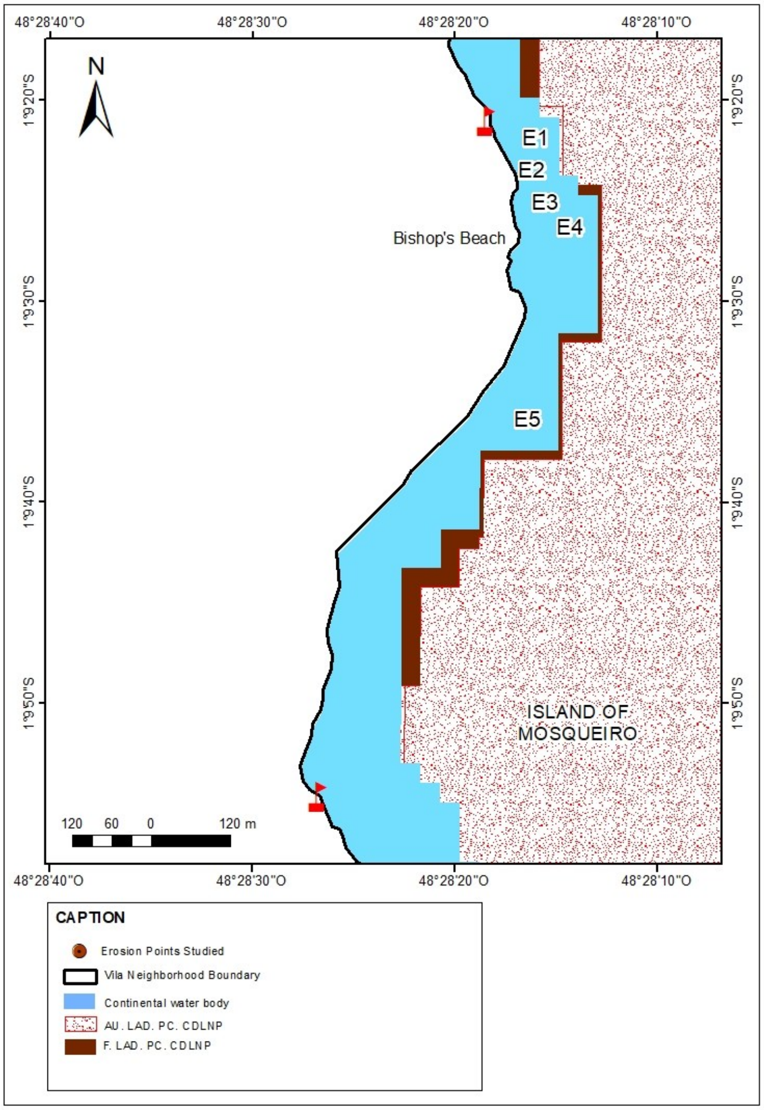

Figure 8 – Geoenvironmental Map of Praia do Bispo, Mosqueiro/PA.
Source: Authors (2023).

Points E1 and E2 are located in the scenario "AU. LAD. PC. CDLNP", characterized by urban areas with residential buildings, recreational spaces, and infrastructure such as sidewalks, leading to a loss of landscape aesthetics. These human activities can increase the frequency and intensity of natural processes that cause impacts such as coastal erosion (including storm surges), floods, mass movements, siltation of drainage channels, and fluvial erosion. These areas are associated with Dystrophic Yellow Latosol, which are mineral soils with a latosolic horizon. They are highly weathered, deep, with a sandy-medium to medium texture, good drainage, good porosity, good permeability, low chemical fertility, low organic matter content at depth, and are typically found in flat and gently undulating reliefs (Albuquerque, 2013). These points are also located in a Coastal Plain (PC), characterized by sediment movement caused by water in a low-slope environment, consistent with the local geomorphology.

Points E3, E4, and E5 are located in the scenario "F. LAD. PC. CDLNP", which, unlike the "AU. LAD. PC. CDLNP" scenario, features intact forest cover. Despite the occurrence of landslides, the forest does not provide sufficient buffering to counter this imbalance, which is believed to have developed over time due to the region's climatic conditions. Rainfall is a significant climatic factor contributing to soil erosion. Raindrops strike the soil, initiating the erosion process by dislodging soil particles at the impact site, transporting these detached particles, and imparting energy in the form of turbulence to surface water (BARBOSA, 2012). Additionally, this area is affected by tidal forces, as it is exposed to semi-diurnal tides with maximum amplitudes of 3.9 m during the spring tides in March, April, and September (BRASIL, 2018). There is also significant wave activity, with waves reaching heights of 1 m to 1.5 m under N-NE quadrant winds, which are stronger from July to November. The shoreline is further influenced by a seasonal rainfall pattern, with the highest concentration of precipitation occurring from January to March (França et al., 2020).

4. Final considerations

Geoenvironmental studies are essential for diagnosing areas affected by erosive processes and supporting decision-making to minimize these damages. The data overlays and information analysis for Praia do Bispo, on Mosqueiro Island, in Belém do Pará, identified two distinct geoenvironmental scenarios that experience the same impact: anthropized areas and vegetated areas affected by erosion processes. These scenarios exhibit dynamic behavior, with noticeable factors related to urban occupation, such as the installation of concrete retaining structures, leveled terraces, and asphalt paving. Additionally, the conditions of the biophysical environment, represented by vegetation cover, play a significant role. Although both factors can be causes and solutions for erosion—contributing to both impact and containment— their effects are compounded when combined with other factors such as climate and tidal forces.

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