American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)
ISSN (Print) 2313-4410, ISSN (Online) 2313-4402

http://asrjetsjournal.org/

Landscape Transformation:Temporal Evolution of the Erosion Process on a Hillside on the Island of Itamaracá / Brazil

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Abstract

Urban planning is important to guarantee the quality of life for society, as it proposes spatial planning and problem solving, especially those related to land use. Thus, it was proposed to perform an evaluation of actions that promote and/or accelerate the erosive processes on a hillside located in Island of Itamaracá/BR. The “interaction networks” and “land use maps” techniques were used in combination, which resulted in a more accurate environmental assessment, as well as the use of models for future estimates. The results pointed to medium risk for the environmental indicators of “occupation types” and evidence of collapse”, and high risk for “urban density” and “vegetation” indicators. It has also been predicted that over the years, the urban sprawl in the area will continue to grow until it reaches stability due to the total occupation of useful areas as well as that the growth rate for vegetation will be negative. Thus, there is a need to mitigate environmental damage in the short term, in order to avoid the occurrence of accidents in the hillside area.

Keywords: Water erosion; Interaction networks; Land use and occupation; Environmental risk.

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1. Introduction

Creating activity programs that include factors such as land use is fundamental for socioeconomic development. The impact of disordered growth on the expansion or emergence of cities, when not scaled, may trigger hazy urban complexes [1, 2]. Urban planning is the act of ordering cities and solving their problems, which, depending on the locality, are numerous. The quality of people's lives is the fundamental objective of this planning, based on responsibility and rationality of both the public agencies and the community in genera [3]. Social rationality can be achieved through systematic studies that present solutions to problems arising from the impact of urban growth as well as through the implementation of policies and legislation that guarantee the maintainability of the system. A survey conducted in 2017 showed that 95% of Brazilian municipalities had some legislation or project that addressed the issue of urban planning; however, they are inefficient [4], 2017).When traveling through the various Brazilian municipalities, one may notice the existence of irregularly occupied areas, with poor infrastructure, constituting the favelas, currently named as needy communities. Social conflicts associated with the search for urban spaces for housing and livelihoods promote the migration of minorities in general to areas lacking basic services [3]. The negative results of irregular occupations are already perceived by the population, especially in risky areas, such as the ones near hillsides. They are generally prone to water erosion processes, which are caused by water flows and lead to landslide phenomena [5, 6]. The phenomena caused by anthropic actions have a direct impact on the welfare of the region where they occur [7]. Through natural transport processes, the result of some actions is perceived in neighboring regions. Thus, even knowing that the urban area constitutes a small portion of the total land surface, it has a disproportionate influence on its surroundings, especially in terms of natural resources [8]. In order to monitor the recurrence of environmental impacts and to contribute to decision making in urban planning management, methodologies for environmental impact assessment that identify indicators as well as the causes and effects of environmental degradation can be used. However, these methodologies are subjective in approaching the physical environment, making it necessary to employ complementary techniques, such as remote sensing. Mapping and monitoring areas through the use of satellite imagery are named remote sensing. This technique is an important tool for understanding human actions on ecosystems, facilitating the finding of the emergence of environmental imbalance [9]. The remote sensing images are useful for tracking the growth of urban areas, providing timely information of land cover [8]. Remote sensing data through the Geographic Information System (GIS) are made compatible and become visual presentations. The information constructed with the GIS can be transformed into maps about the investigated area, which serve as a basic input in planning and management decisions [10]. In this context, this study aims to conduct an environmental impact assessment through interaction networks and temporal analysis of land use and occupation in a hillside area located in the Island of Itamaracá, Pernambuco/BR, due to its tourist importance and where a modification of the native vegetation for urban installations is noticed, leading to an acceleration of the soil erosive processes.

2. Methodology

2.1. Study area

Island of Itamaracá is a municipality that represents an important historical value. Its name comes from indigenous people and means “singing stone” [11]. The local economy is based on tourism, including tourism related to beaches, historical heritage, ecotourism, and projects to protect marine species [12]. Part of Recife Metropolitan Region (RMR), Island of Itamaracá is 44 km away from the capital of the state of Pernambuco, Recife. It is limited to the north with the city of Goiana; to the west, with Itapissuma; to the south, with Igarassu; and to the east, with the Atlantic Ocean. It is approximately 40 meters above sea level. The selected hillside is referenced under the coordinates 07 ° 46 '9 "S 34 ° 50' 28" W, as shown in Fig. 1.

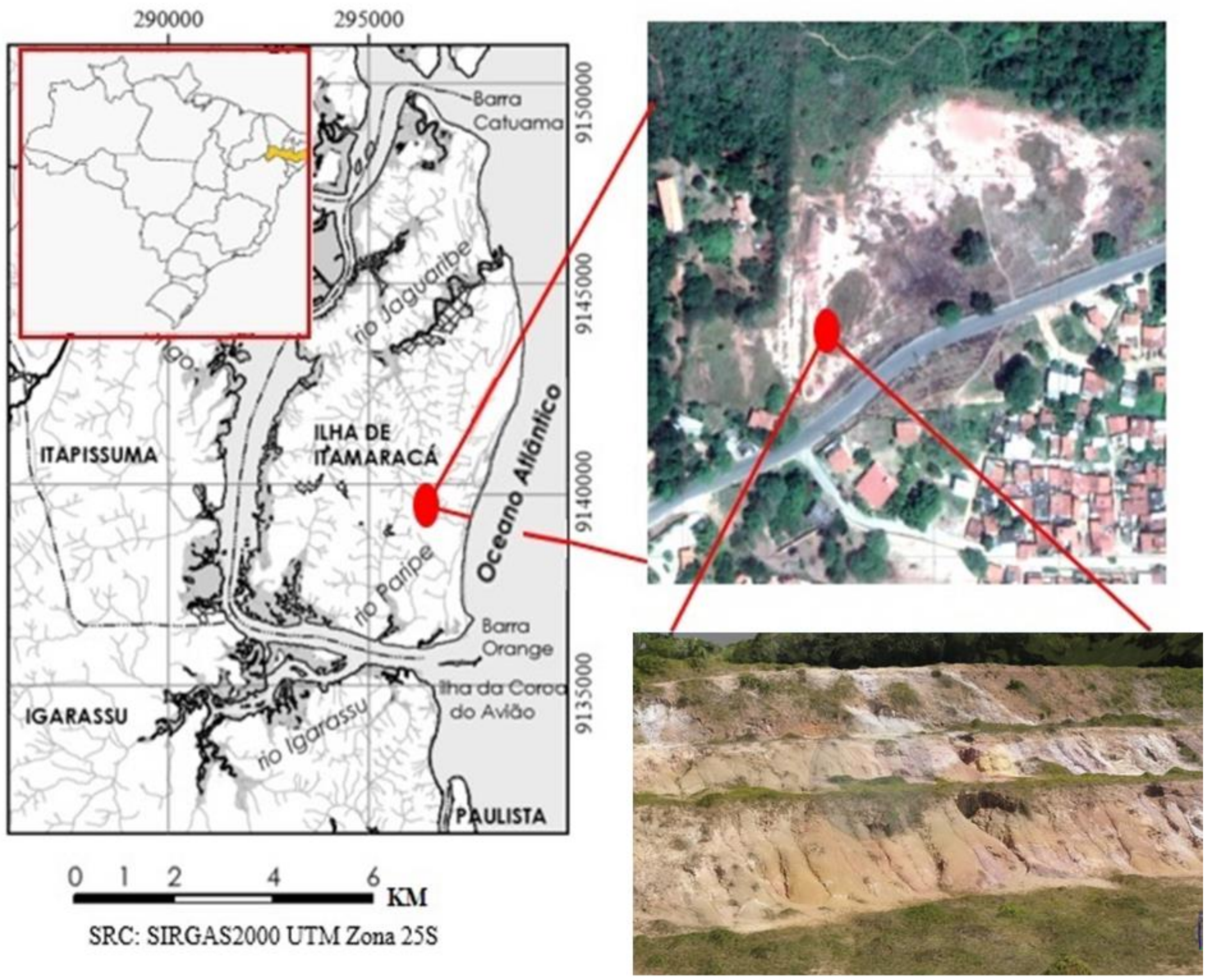

Figure 1: Study area location.

The municipality registered 6,026 new inhabitants between 2000 and 2010, with an average annual growth rate of 3.27%. The population living in the island in 2000 was estimated at 15,858 people. In 2010, a population of 21,884 people and a demographic density of 328.17 in habitants/km² were estimated [13]. Regarding the physical aspects, the island has vegetation consisting predominantly of evergreen restinga forests. The climate is tropical (hot and humid), according to the Koppen classification, and the annual average temperature varies between 25oC and 27oC.Monthly average rainfall is estimated at 100 mm, and the formation of barriers occupies most of its territory [14, 15, 16]. The physical aspects of the study area are shown in Table 1. The area was a gravel quarry, which is the product of alteration of quartz-feldspatic rocks, such as granites and gneisses. The deposit was decommissioned around 1988. The hillside, which is about 14 meters high, is currently part of a private property.

Table 1: Physical aspects of the study area

Physical aspect	Study area	Relevant remarks
Vegetation	There is no vegetation on the baseline of the hillside	Anthropic action removing native vegetation for urbanization or use for coco-bahia planting
Climate	Tropical hot and humid; Tropical rainy dry summer; Rain concentration between March and August	Precipitation affects the transport of particles through the flow, favoring erosive processes.
Relief	Hill	-
Soil	Clay soil predominates.	Presence of clay, which may contain sand; very erodable soils.
Geology	Barriers, Gramame, Maria Farinha and fluvial deposits.	Clear, incoherent fine to medium-grained feldspar sands with alternating clays; may be along with Gramame Formation.

2.2. Construction of interaction networks

Interaction network methods allow the identification of direct and indirect environmental impacts and their interrelationships. The main advantage of the method is the easy understanding of secondary and indirect impacts and the possibility of introducing statistical parameters, allowing future possible modifications to be estimated [17, 18, 19].Thus, a Cause and Effect Diagram, also known as Ishikawa Diagram, has been designed to represent chains of impacts associated with their possible causes. The environmental indicators included were: (1) occupation types; (2) population density; (3) reduction of vegetation areas; (4) evidence of structure collapse.After the construction of the interactions, it was necessary to classify the degree of risk of each indicator to favor environmental degradation. Risk analysis becomes critical for territorial planning and to maintain the active participation of political actors [20]. Thus, the degree of risk classification follows the parameters [21]: • Low level - There is no obvious risk of geotechnical or hydraulic accidents; specific geotechnical stabilization interventions are not required, following only general recommendations; • Medium level - There is a risk of geotechnical or hydraulic accidents of small and medium size; • High level - There is a risk of serious geotechnical or hydraulic accidents.It is noteworthy that there was a study site visit to find out if the causes included in the Cause and Effect Diagram were really related to the area and to visually evidence the effects of erosive processes, such as: building pathologies and characteristic features of soil erosive behavior (pipins, sinkholes, ravines or gullies).

2.3. Land use and Occupation Maps

The fieldwork consisted of visits to the study area for diagnosis. This diagnosis, coupled with photointerpretation and satellite image analysis, not only served as a database, but also allowed a recognition of the impacts on the hillside dynamics caused by anthropogenic factors. The studied hillside data were obtained from the Planning and Research State Agency of Pernambuco - CONDEPE/FIDEM. The scale of the supplied orthophotocards of 1975, 1989, 1998, and 2018 were 1: 10000.

2.4. Interaction network combined with remote sensing

The combination of the interaction network method with remote sensing resources allows one to detect temporal aspects of a region, the system dynamics, and the relative importance of environmental impacts. Thus, statistical parameters were introduced in the land use and occupation data, which identified changes in the hillside over the 43 years observed (1975-2018), in order to, then, predict the site scenario in 2028.

2.5. Prediction of future land use and occupation scenario

A prediction was made for 2028 of the evolution of the use and occupation of the hillside from the arithmetic and geometric mathematical models. The arithmetic method is based on the assumption that the population evolves constantly in a straight line, which can be prolonged to the desired date, or even that follows an arithmetic progression, according to Equations 1 and 2. The geometric method is based on assumption of population growth in geometric progression, using logarithmic tables for this calculation, as presented in Equations 3 and 4 [22].

$$P = P_0 + r(T_x - T_0) \quad (1)$$

$$r = \left(\frac{P_2 - P_1}{T_2 - T_1}\right) \quad (2)$$

$$P = P_0 * e^{q(T_x - T_0)} \quad (3)$$

$$q = \frac{\ln P_2 - \ln P_1}{T_2 - T_1} \quad (4)$$

Where is the population for the estimated year; represents the current population; is the annual growth factor for the arithmetic method; and are, respectively, the projection year and the current year. For determining the annual growth factor, represents the population of the initial year, the population of the last census, are the initial year and the year of the last census, in that order. Finally, is the annual growth rate for the geometric method.

3. Results

3.1. Cause-Effect Diagram

With the elaboration of the Cause and Effect Diagram, the possible sources of impacts in an interaction network with their respective environmental indicators were evaluated, as shown in Figure 2. Soil erosion was the environmental impact/final effect considered in this study. Thus, the causes were based on the findings of other investigations, consulted during the theoretical reference survey, which are: Occupation near the edge of the hillside; implementation of road system; Expansion of urban sprawl; annual population growth; Suppression of native vegetation; soil exposure; Soil characteristics; storm water concentration; single rigid structure implementation (shoring, embankment, piping).

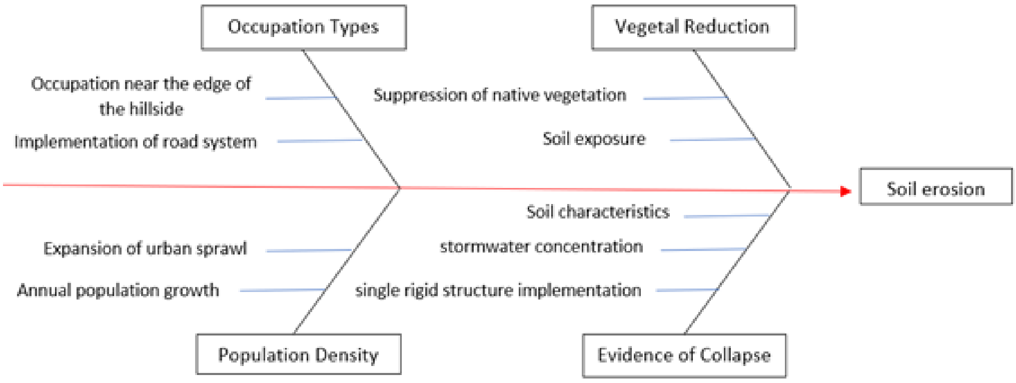

Figure 2: Cause and Effect Diagram.

With the diagram, it is noticed that for each environmental indicator there are actions/causes that directly affect the environment, causing its degradation. However, these same actions become secondary if analyzed from another indicator, proving the interaction between them. Therefore, mitigation actions should encompass as many environmental indicators as possible.

3.2. Remote sensing data

Table 2 shows the spatial distribution and the qualitative results of the use and coverage assessment for the hillside located in Island of Itamaracá, based on the digital satellite image classification for 1975, 1989, 1998, and 2018. The observed classes were: (1) exposed soil, (2) vegetation, (3) urban sprawl and (4) road system.

Table 2: Land use and occupation data

Class	Area (m²)				% study area			
	1975	**1989**	**1998**	**2018**	**1975**	**1989**	**1998**	**2018**
Exposed soil	19940.49	14174.46	6864.89	39574.18	20.79	14.78	7.16	41.25
Vegetation	73254.61	77097.62	83633.97	37414.12	76.36	80.37	87.18	39.00
Urban sprawl	194.28	295.80	2434.33	12263.09	0.20	0.31	2.54	12.78
Road system	2537.84	4358.53	2997.64	6676.95	2.65	4.54	3.12	6.96

To qualify the temporal changes, from the orthophotocards, it was necessary to perform a restitution, according to Figure 3. The Geocentric Reference System for the Americas 2000 (SIRGAS2000), the new reference system for the Brazilian Geodetic System (SGB) was used. The hillside is in zone 25 S for the Universal Transverse Mercator (UTM) coordinate system.

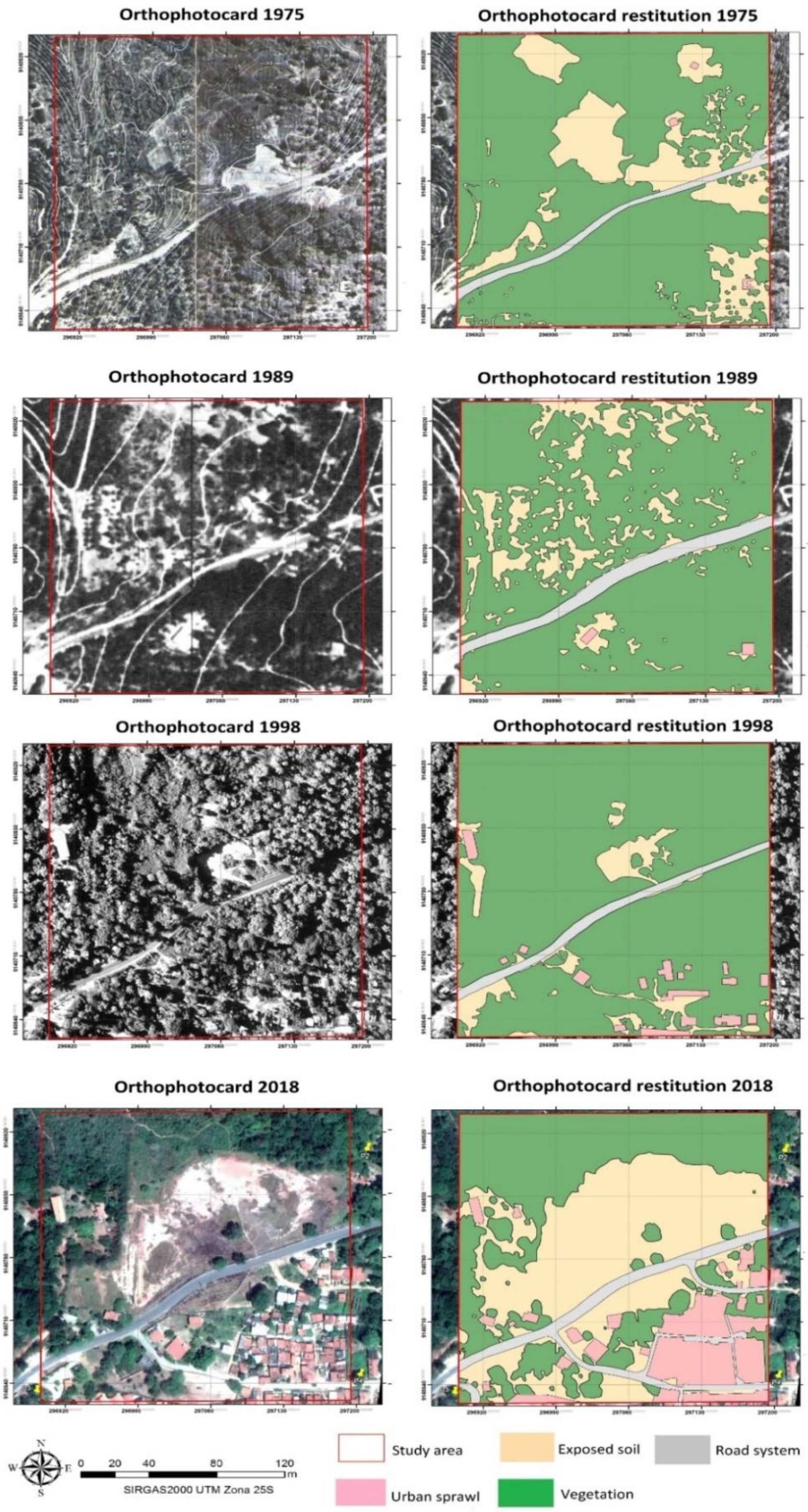

Figure 3: Use and occupation of the hillside area in 1975, 1989, 1998 and 2018 [22].

4. Discussion

4.1. Evaluation of environmental indicators

In site visits, ravines/furrows were found on the hillside surface, characteristic of erosive soils. Around the hillside, it was possible to notice: (1) unprotected areas of vegetation, (2) reduction of useful areas for occupation due to the appearance of critical points (susceptible to erosive processes), (3) imprisonment of municipal solid waste (MSW) near the rigid structures and (4) change in the permeability of the soil due to the construction of waterproof areas. The studied hillside is located on the banks of the PE-035 highway. In general, road drainage directs rainwater to the sides of the road where it is drained. In situations of over-estimated rainfall, flooding and/or drainage obstruction and subsequent infiltration at the base of the hillside may occur. The drainage network and relief associated with the physical characteristics of the area are directly related to the susceptibility of the site [23]. The hillside is part of a private area and no buildings near the verges were identified, while the buildings in neighboring limits had a low construction standard. No sewage disposal was observed directly in the environment neither containment works were identified. Land use screening allows identify areas prone to surface erosion. Thus, the indicator "type of occupation" was classified as medium risk. [24]. The soil characteristics of the hillside were investigated [25]. Through Crumb test and comparative sedimetometric (SCS), it was verified that the soil has a dispersive character. Through the granulometric curves, the soil was classified as silty sand. The structure of the hillside underwent a recalculation, where two berms and a channeled drain system were inserted to increase its stability [26]. Due to the slope of the hillside, rainwater tends to flow under its surface, carrying soil particles, and concentrating on the built-up berms. Thus, that erosion rate and soil life expectancy are more sensitive to changes in land use than rainfall changes [27]. In this context, the indicator "evidence of collapse" was classified as medium risk because, even after the implementation of the surface drainage system and geotechnical stabilization, features of erosive processes and the lack of regular monitoring were observed. Crossing data on "occupation types" (occupations near the berms and road system deployment) and "collapse of evidence" (soil characteristics, stormwater concentration, and rigid structure deployment) is imminent risk, this classification represents an area occupied by low-standard housing with potential for natural disasters, and short-term intervention should be undertaken [23]. Environmental causes associated with the "population density" indicators (urban sprawl expansion and annual population growth) and "vegetation reduction" (native vegetation suppression and soil exposure) were portrayed along with the temporal analysis of land use and occupation, as in subtopic 5.2.

4.2. Temporal analysis of land use and occupation

The total area of the investigated hillside comprises 95,927 m². In 1975, the urban sprawl represented 0.2% of the territory. However, in 2018, the sprawl expanded approximately 13 times. This growth in 43 years is associated with spatial modification, in which the vegetation has been reduced to enable new construction and, consequently, the increase of waterproofed areas. As the expansion of urban sprawls is registered, it is possible to notice the expansion of the road system, given the need to create access routes to new addresses, facilitating the movement and transit of people and goods. Between 1975 and 2018, the road system in the study area was expanded by 4,139 m². Between 1975 and 1998, there was an increase in the area occupied by vegetation and a reduction in the area of exposed soil. However, in 2018 the scenario changed, so that about half the vegetated area was reduced and the exposed soil area grew a total of 32,709 m². These changes raise concern regarding the formation of new lands susceptible to landslides, as shown in Figure 4.

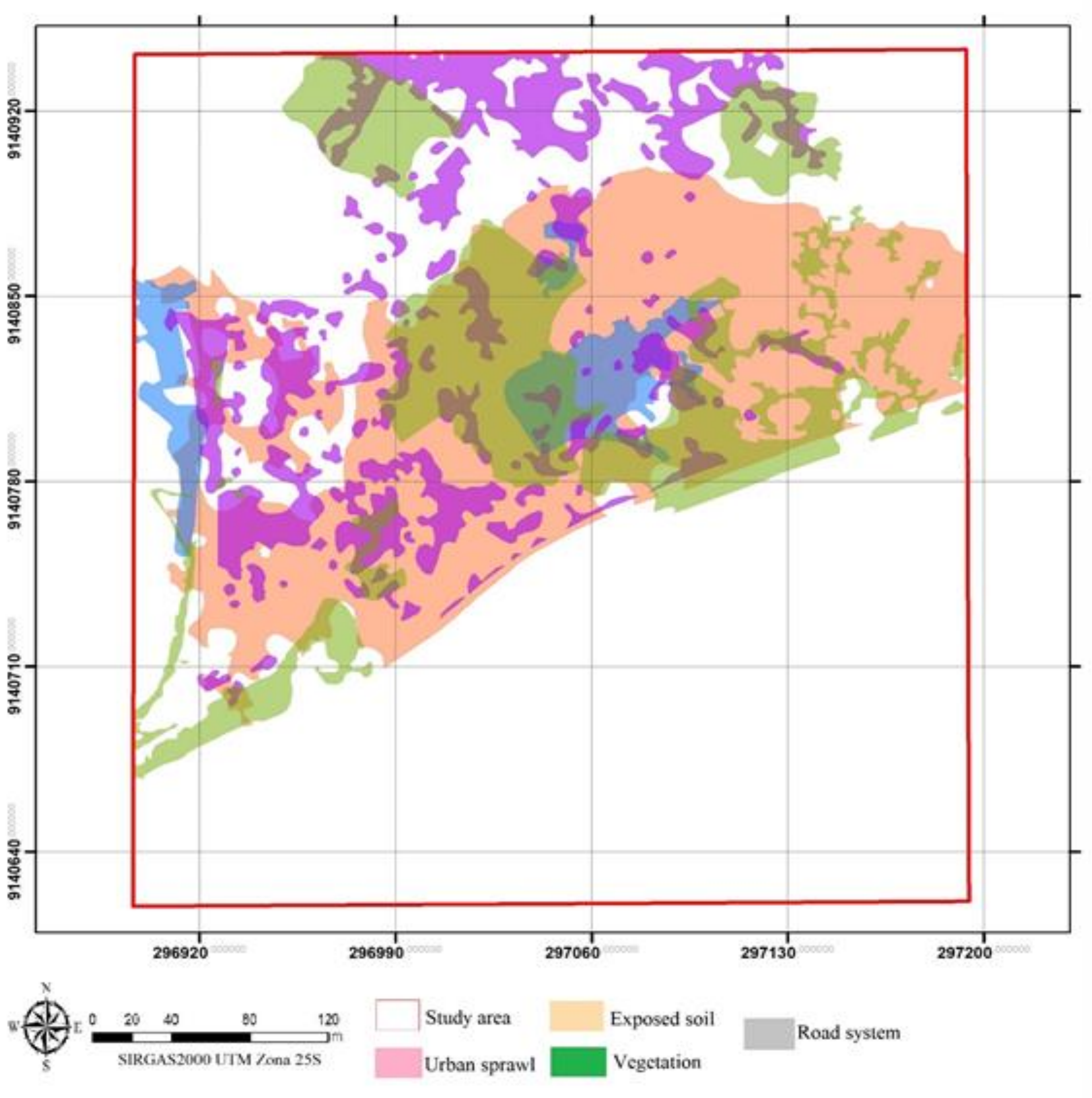

Figure 4: Evolution of the slope area between 1975, 1989, 1998 and 2018.

The alarming growth of the exposed soil parameter, which occurred from 1998 to 2018, may have its roots in the old gravel deposits that were exploited in the region combined with the dispersive nature of the soil. The lack of vegetation cover in the soil makes the place prone to direct incidence of rain on the ground surface, making it unable to withstand the rapid infiltration of water, further accelerating surface run off that will carry the fines of the soil [28, 29]. It is still important to ascertain the cause of the large expansion of urban sprawl in the area surrounding the hillside, given the small annual rate of 3.7% of population growth in Island of Itamaracá, compared to 13.3% in Recife, the state capital. In this context, the indicators “urban density” and “vegetal reduction” received a high-risk classification due to the possibility of serious geotechnical or hydraulic accidents. From the finding of unrestricted land use and occupation, due to the increase of urban population, it is noticed that urban planning and public management were not able to absorb the population increase and did not offer the basic infrastructure for the new urban agglomerations. This configuration leads to the emergence of illegal settlements, degradation of natural resources, reduction of biodiversity, and emergence of heat islands [30, 31, 32].

4.3. Urban planning management and future perspectives

By relating the results of environmental interactions and the temporal analysis, it can be noticed that there was a constant urban growth in the study area, with a peak in 2018. On the other hand, the concern with the environmental preservation did not follow this scenario, with the reduction of vegetation, that is, reduction of biodiversity. Other authors concluded the same and further stated that economic growth and public concern have a nonlinear relationship [33]. Itamaracá, being an island, is constituted of coastal areas that tend to densify urban occupation, modifying the area of native vegetation and accelerating erosion processes, as well as shoreline retreat. The population density can be considered as a control variable, since areas of urban agglomeration demand stronger environmental governance because they lead to worsening pollution and environmental degradation [34]. Monitoring tools contribute to urban planning management as they provide timely information, whether past or future forecasts, from different territorial points. Forecasts can be based on the mathematical method and assume that the population grows according to a definite mathematical formula derived from experience. Land and use is often considered a static factor in landslide risk studies [35]. By applying the arithmetic and geometric mathematical method, it was possible to predict the 2028's situation for land use and occupation in the hillside area, located in Island of Itamaracá /BR, according to Table 3. Both methods were used for comparative purposes, because, the geometric method generally has lower estimates than those obtained by the arithmetic method in the intercensity calculations [36].

Table 3: Land Use and Occupation Prediction 2020.

Class	2028					
	Arithmetic Method			Geometrical method		
	Annual growth rate	Area (m²)	% of study area	Annual growth rate	Area (m²)	% of study area
Exposed soil	456,60	44.140,15	42,21%	0,01594	46.412,92	41,28%
Vegetation	- 833,50	29.079,12	37,26%	- 0,01563	32.001,86	36,64%
Urban sprawl	280,67	15.069,79	13,37%	0,09640	32.154,70	15,02%
Road system	96,26	7.639,53	7,16%	0,02250	8.361,40	7,06%

It is possible to identify a difference between the results of mathematical methods. As predicted, the values of the areas obtained with the geometric method are larger than those of the arithmetic method. Analyzing the forecast for 2028, there is the growth of urban sprawl and its tendency to stabilization because, over the years, the occupation will extend to the entire useful area for construction. As a result, it is observed that only the vegetation growth rate has negative value. Different development patterns contribute to land cover change and conversion and increasing settlement densities may have a significant influence on the rate of deforestation per unit of population growth [37]. The area occupied by exposed soil also shows growth in 2028, thus confirming the results mentioned in the evaluation of environmental indicators, regarding the reduction of useful areas of occupation mainly due to the appearance of water erosion processes. For the problem management, the use of sustainable land and soil management practices, such as conservation and restoration measures [38, 39].

5. Conclusion

Using the interaction network tool for environmental impact assessment along with land use and occupation maps, a remote sensing technique, it was possible to identify that the environmental indicators of “occupation type” and “evidence of collapse” presented a medium environmental risk degree for the hillside area located in Island of Itamaracá/BR. Moreover, the “urban density” and “vegetal reduction” indicators were classified with high risk, due to conditions that favor the occurrence of serious geotechnical or hydraulic accidents. Characteristics of erosive processes can already be noticed in the studied location. Thus, negative environmental impacts need to be measured and monitored on a temporal and spatial scale to help urban planning and decision-making by the public sector as to what type of mitigation solution would be most effective to the environmental degradation verified. Through mathematical models, it was predicted that by 2028 there will be an increase in urban sprawl, exposed soil area, and the road system in the hillside region. Furthermore, the area occupied by vegetation will be reduced. However, it was concluded that urban growth will tend to stabilize, due to the lack of areas suitable for construction as well as that new points prone to erosion will emerge, and public intervention will be required in the short term.

6. Recommendations

For future research, it is recommended annual monitoring of the area to check the advance of urban occupation and its possible stabilization. Also, it is suggested to include the classes: (1) “local temperature” to check for the existence of microclimates / heat islands; (2) "wetlands" to check the locations where water is accumulated, which can enhance the erosion.

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