Mapping of the retrogradation and coastal vulnerability of the seashore at Barra de São Miguel County, Brazil

HENRIQUE RAVI ROCHA DE CARVALHO ALMEIDA
UNIVERSIDADE FEDERAL DE ALAGOAS
Brazil

Valdir do Amaral Vaz Manso
Departamento de Geologia,
Universidade Federal de Pernambuco, Brasil.

Rochana Campos de Andrade Lima
Centro de Tecnologia,
Universidade Federal de Alagoas, Brasil

Djane Fonseca da Silva
Instituto de Ciências Atmosféricas,
Universidade Federal de Alagoas, Brasil

Abstract

It is necessary to expand knowledge regarding physical environment in order to establish rational guidelines for coastal areas use, thus, this research aimed to determine retrogradation rates and vulnerability of the seashore at Barra de São Miguel county to RSL rise, as well as to suggest building zone limits. Therefore, in loco environmental observations were obtained between 2016 and 2017. In order to categorize vulnerability level, the coast was divided into section A (A_1, A_2 e A_3) and section B. Results show that approximately 57% of the coast (Section A) is threatened, presenting high vulnerability level. In contrast, section B presented low erosion vulnerability. Retrogradation indicated that even in the optimistic scenario, retreats will be high, reaching all buildings in the section A. Section B, despite high environmental preservation level, would still exhibit retreats of 15.1m. Coastal building zone limit (CBZL) demonstrated that previous results adoption would be enough to absorb future impacts generated by RSL rise. Thus, it is valid to affirm that results obtained are important to comprehend coastal environment and could be used as a guiding source to monitoring and management of the region.

Keywords: coastal building zone limit, coastal erosion, coastal vulnerability, coastal management

1. Introduction

In the last years, there was an expressive increase in elaboration and implantation of spatial development plans, directed to the management of coastal counties. The reason for it is in the fact that, among environmental units, the coastal zone is the most likely for socio-economic activities implantation that disturb natural environment, affecting coastal and marine ecosystems balance (ASSIS, 2007).

In order to preserve environmentally protected spaces, considering its importance and fragility, it is common to adopt strategies to evaluate the territory by means of its zoning, pointed by Silva and Santos (2004) as the "identification and delimitation of environmental units within a specific physical space, concerning its vocation and fragilities, successes and conflicts". However, it is a consensus that zonings are executed under purely qualitative criteria, according to subjectively structured models with a demand for methodological proposals that identify zones from the selection of mappable environmental attributes (ASSIS, 2007).

Authors as Bruun (1962), Schwartz (1967), Dean (1991), Pilkey (1993), Manso *et al.* (1995), Gruber (2002) and Manso (2012) recognize the importance that interaction between shallow shelves and beach environment represent to the knowledge and management of coastal zones, because they are essential to projects and studies involving the coastal region, such as issues related to progradation and retrogradation of beaches; artificial beach feeding projects or exploration of submerged deposits, preventing from considerable damages on the surrounding coastal environments.

Besides these factors, prediction of sea level elevation is a variable that should be considered in the prognosis of coastal line variation due to erosive processes intensified by the increase of glaciers melting and historical trend of climatic temperature elevation (MUEHE, 2004).

According to Wong *et al.* (2014), the *Intergovernmental Panel of Climate Change* (IPCC, 2013) estimated a pessimist scenario for coastal regions with sea level rise, indicating elevation over 1 meter until 2100. According to this prediction, absorption zones of this impact must be established in order to help coastal management, even if this scenario might never become reality, as it is an estimate.

In this context, due to the need to increased knowledge about the physical environment to establish rational guidelines to use coastal areas, this study aimed: (i) define coastal retrogradation levels (erosive risk zones); (ii) categorize coastal vulnerability level to marine erosion; and (iii) define coastal building zone limit for the protection and maintenance of landscape esthetics.

2. STUDY AREA

The study area comprehend the coast of Barra de São Miguel county (Figure 1), located in the south of the state of Alagoas. The area comprises approximately 10 km of shoreline and surrounding shallow continental shelf, delimited by the surrouding rectangle through plane UTM coordinates: N = 8908288m
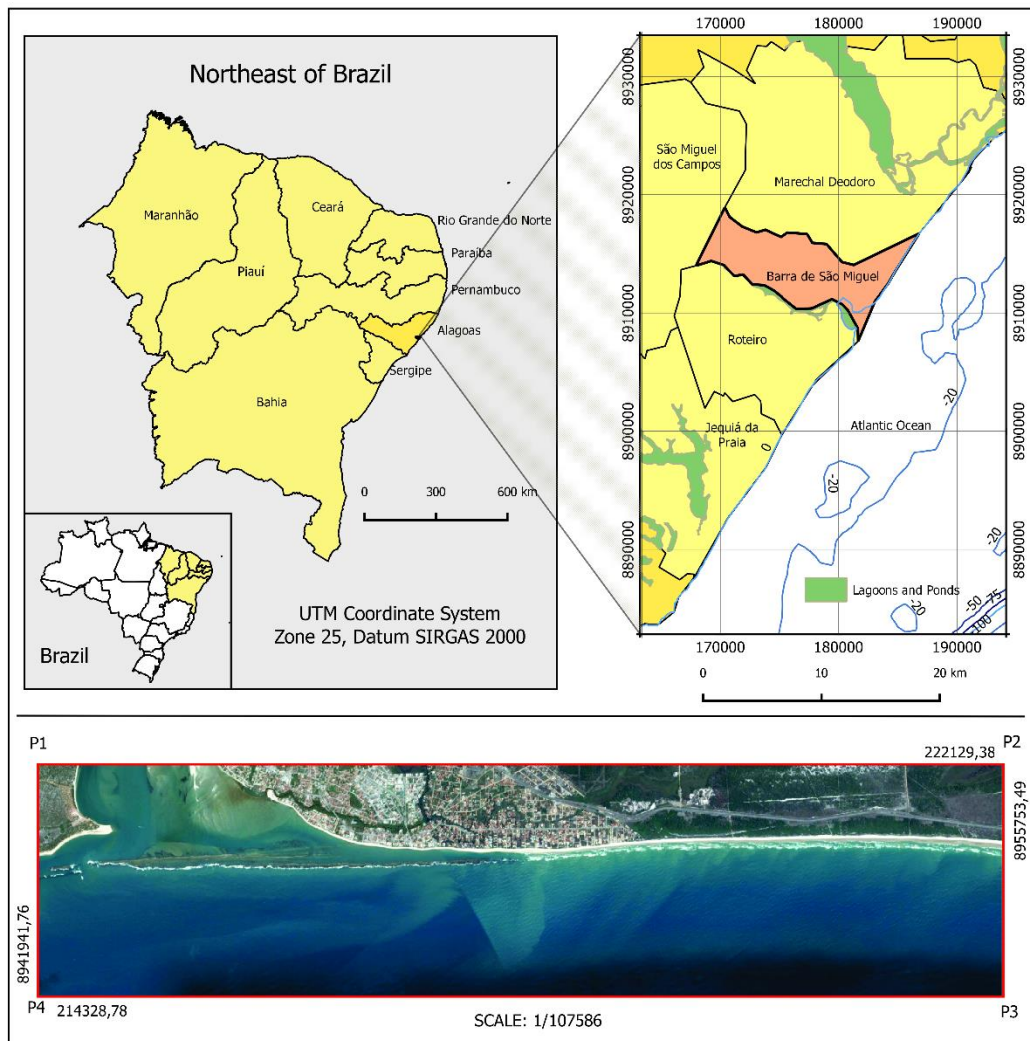
E = 180428m; and N = 8916114m, E = 187956m, located in the time zone 25, Datum SIRGAS 2000.

Figure 1 – Map of location of the study area. Source: Author.

According to KÖPPEN classification, the coast is located in a region of type AS' climate, presenting rain during the winter, dry summer and temperatures from 20 to 25ºC (ARAÚJO *et al*., 2006).

Regionally, the county is located on Sergipe-Alagoas Sedimentary Basin which is one of the sedimentary basins along the Brazilian coast formed during the opening of the South Atlantic Sea in the end of Jurassic and Cretaceous periods (SANTOS, 2004).

The current stage of depositional evolution of Alagoas Sub-basin is characterized by the variation of sea level and erosive agents, which enable accumulation of marine, fluvial, eolian and fluvial-lagoon sediments that compound the Quaternary coastal plain (SANTOS, 2004).

Regarding width of the continental shelf of Sergipe-Alagoas Basin, it varies from a maximum of 42 km in front of Maceió, to a minimum of 18 km in the southern region, presenting a flat profile since the beach zone until the edge of the shelf, where declivity sharply accentuates. The wide and flat feature is the result from erosive and depositional activities, intimately linked to various marine regressions and transgressions associated to periods of global glaciation and deglaciation (COUTINHO, 1976).

From a geomorphological view, two well-characterized units are defined within the study area: Coastal Trails and Coastal Plains, located within the typical modeled of dissecation and accumulation, respectively. According to Santos (2004), Costal Trails represent the most characteristic geomorphological unit of the coast of Alagoas, composed by the Barreiras Formation. This morphology originates fossil cliffs, colluvial ramps, dissected tabuliform interfluves, colluvial-alluvial terraces, river valley slopes, and structural estuary slopes.

The Coastal Plain occupies approximately 9.5 km within the study area, entering towards inland for 2.5 km in direction to the fluvial-lagoon sediments surrounding Roteiro Lagoon-Estuarine System, and 1.8 km in the north/east direction of the inter-municipal boundary between Barra de São Miguel and Marechal Deodoro.

Regarding sedimentary balance along the coast, it is characterized by an erosive trend in almost the entire extension, due to the presence of active cliffs of the Barreiras Formation and Mesozoic rocks of Alagoas Basin; nearly absence of plains and Pleistocene terraces; frequent presence of alignments of beachrocks, characterizing coastal retrogradation; and the occurrence of dune-fields, in which sediments from the inner continental shelf are no longer available for coastal progradation (DOMINGUEZ, 1995).

The great morphodynamic diversity of the observed beaches is the result of interaction between various geological and climate elements on the coast, presenting different erosive (retrogradation) and/or depositional (progradation) behaviors in different regions (ARAÚJO *et al.*, 2006).

Anthropogenic interventions and high level of occupation of the coast are responsible for environmental problems related to marine erosion affecting the region. However, marine erosion is also noticed at more urbanized regions within the coast of Alagoas, from the border with the state of Pernambuco until Barra de São Miguel County (ARAÚJO *et al.*, 2006).

Thus, the lack of historical information about Relative Sea Level (RSL) in the study area, as well as in the state of Alagoas, reflects the great coastal vulnerability at the moment, as it is not even possible to guarantee if the erosive process observed in some parts of the coast is a local, regional or global phenomenon.

3. METHODOLOGICAL PROCEDURES

3.1 Coastal Retrogradation

Establishment of the coastal retreat or coastal retrogradation (erosive risk zone) is related to the quantification of the shoreline retreat, associated to the prognosis of average sea level rise, estimated by the *Intergovernmental Panel of Climate Change* (IPCC, 2013) in about 48 cm to 1 m until 2100 (Wong *et al.*, 2014), as well as its modeling agents, such as wind, waves, granulometric composition and ocean currents.

Retreats (R) throughout the coast in the study area were defined by the equation proposed by Bruun Rule (1962), idealized for sandy beaches (Equation 1). Thus, a survey of temporal data related to sedimentology, bathymetry, oceanography, topography and climate was performed during 2017 and 2018, with observations distributed along the four annual climate seasons.

$$R = \frac{slG}{H} \tag{1.0}$$

So that: Active profile length "l" was obtained measuring the distance between the maximum active profile elevation (coastline altitude "h" and depth of closure "d_1"); "s" is the sea level rise in meters; "G" represents the proportion of erosive material in the active profile, usually equals to 1; and height of the active profile "H" was defined through the equation 2:

$$H = h + (1,75 \times d_1) \tag{2.0}$$

Figure 2 demonstrates that a beach-profile translation for a distance "s", due to RSL rise "a" would cause coastal retrogradation and sediments deposition along the shelf profile equivalent in thickness to the RSL rise "a", in order to obtain a new profile balance (Figure 2).
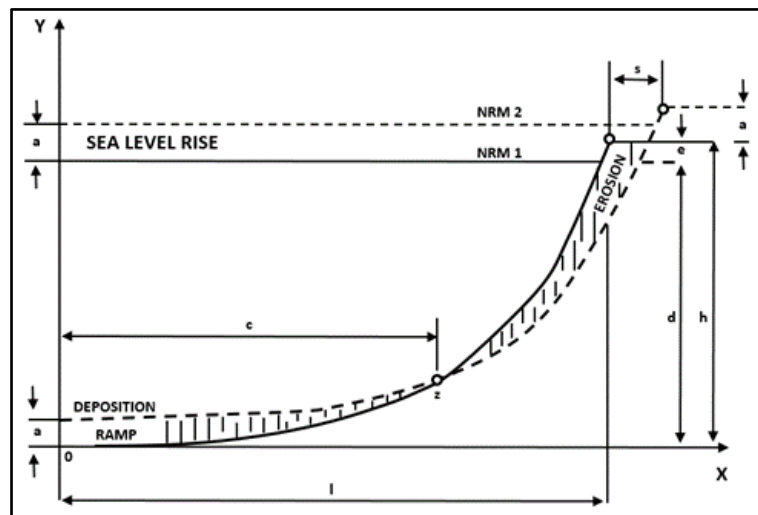

Figure 2 – Bruun Rule: beach translation "s" imposed by a RSL rise "a", resulting in sediments deposition throughout the profile, with thickness "a" to reach a new balance. Where "d" is the depth of the moment RSL1, and "I" is the distance from the profile to the beach. Source: Adapted from Bruun (1954).

According to Nicholls *et al.* (1995), the result of equation 2 represents the sum of the height of the active onshore feature (h), represented by the top of the coastal or beach ridge, or foredune, with profile closure depth for a period of 100 years ($d_1,100$) (Equation 3).

$$d_1,100 = 1,75 \times d_1 \tag{3.0}$$

The value of d_1 was obtained through Hallermeier equations (1981) (Equation 4). It is characterized from extremely significant wave heights conditions on the coastal zone, and defines the limit of the profile depth, where intense sediments transport and extreme changes in the bottom morphology still occur.

$$d_1 = 2\,\overline{H}_s + 11\sigma \tag{4.0}$$

In which: "Hs" is the annual significant mean wave height (m); and "σ" represents annual standard deviation of significant waves.

 In order to obtain diagnosis of temporal behavior of the depth of closure (d_1), calculation was made considering data for each meteorological season and data compiled to the annual period.

Thus, definition of coastal retrogradation (R), based on potential risk evaluation using limits defined by the depth of closure (d_1), allowed deduction of regions within the coastal zone propitious to coastal erosion, defined by the retrogradation line predicted according to the effect of sea level rise.

3.2 Coastal Vulnerability

Physical vulnerability level reveals the fragility, resistance and susceptibility of an environment to dangers and spatial distribution of human occupation. Coastal vulnerability concept is defined as the natural fragility state of a specific coast to erosive events in short or long time scales (LINS-DE-BARROS, 2005b). Effects of different types of coastal features to a sea level rise (Table 1) depend on geomorphological and lithological features in the region, and may vary from nothing to erosion and floods according to the typology presented by Nicholls *et al.* (1995), which requires a specific analysis of coastal compartmentalization, considering these variables (ASSIS, 2007).

Table 1: Response of different coastal features types to a sea level rise.

Type of Coast	Response
Rocky coast (high)	Absense of retrogradation
Rocky coast (low)	Absense of retrogradation
Erosive slopes	Erosion
Sandy beaches	Erosion
Rocky beaches	Erosion
Muddy coast	Erosion or flood
Low slopes	Flood
Swampy coast	Flood
Mangrove	Flood
Coral atoll	Flood

Source: Nicholls *et al.* (1995).

In order to categorize physical vulnerability level of the coast to marine erosion, classification suggested by Dal Cin & Simeoni (1994) was applied to the proposal defined by Nicholls *et al*. (1995), establishing three vulnerability levels:

a) Low: well-developed beach, without containment buildings;

b) Moderate: fragile stability, with fixation buildings in the post-beach area; and

c) High: reduced beach, without post-beach area, strong presence of coastal protection buildings and disorderly occupation.

3.3 Coastal building zone limit

Considering the lack of local legislation to define the coastal building zone limit (CBZL), this study considered guidelines established by the Law 7.661/88 (Brazil's National Coastal Management Plan) and the proposal defined by Muehe (2001), from which is possible to establish a minimum zone for protection and esthetic view maintenance, according to the following criteria (Figure 3):
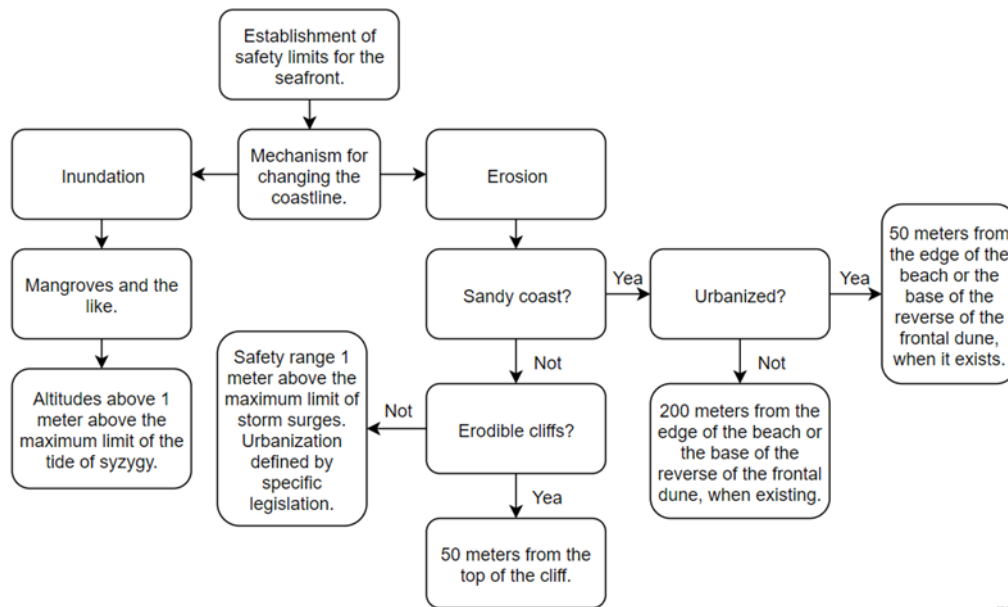

Figure 3 – Coastal building zone limit according to the coastal morphological features.
Source: Adapted from Muehe (2001).

According to Muehe (2001), reduction of minimum limits may occur when there is a progradational trend of the coastline, expressed in annual rates, or if the place is located in sheltered areas, since technically justified, without prejudice to state or municipal competence to establish more restrictive measures.

Lastly, in order to accomplish interpretation and cartographic representation of vulnerability levels of the study area, the coastline was subdivided into two sections and four subsections, according to [Anonymous, 2018], considering different coastline altitudes, active profile width variation, geology, geomorphology and anthropic occupation

4. RESULTS AND DISCUSSION

In order to organize information regarding the impact level of coastal retrogradation, vulnerability and coastal building zone limit over the study area, results were presented and described by subsections, as follow:

4.1 Subsection A_1

It is located near São Miguel and Niquim rivermouths, limited by plane UTM coordinates (8.910.176 mN, 181.296 mE) and (8.911.139, 183.198 mE), Datum SIRGAS 2000, with extension of approximately 2.55 km. Considering sea level rise scenario (S_1) of 0.48 m, estimated as the most likely scenario, this subsection indicated retrogradation (R_1) of 36.88 m. Compared to a pessimist overview ($S_2 = 1$ m), retrogradation (R_2)

would be of 76.88 m. Even in an optimistic scenario, retreats extension already reached existing buildings in the post-beach area (Figure 4).
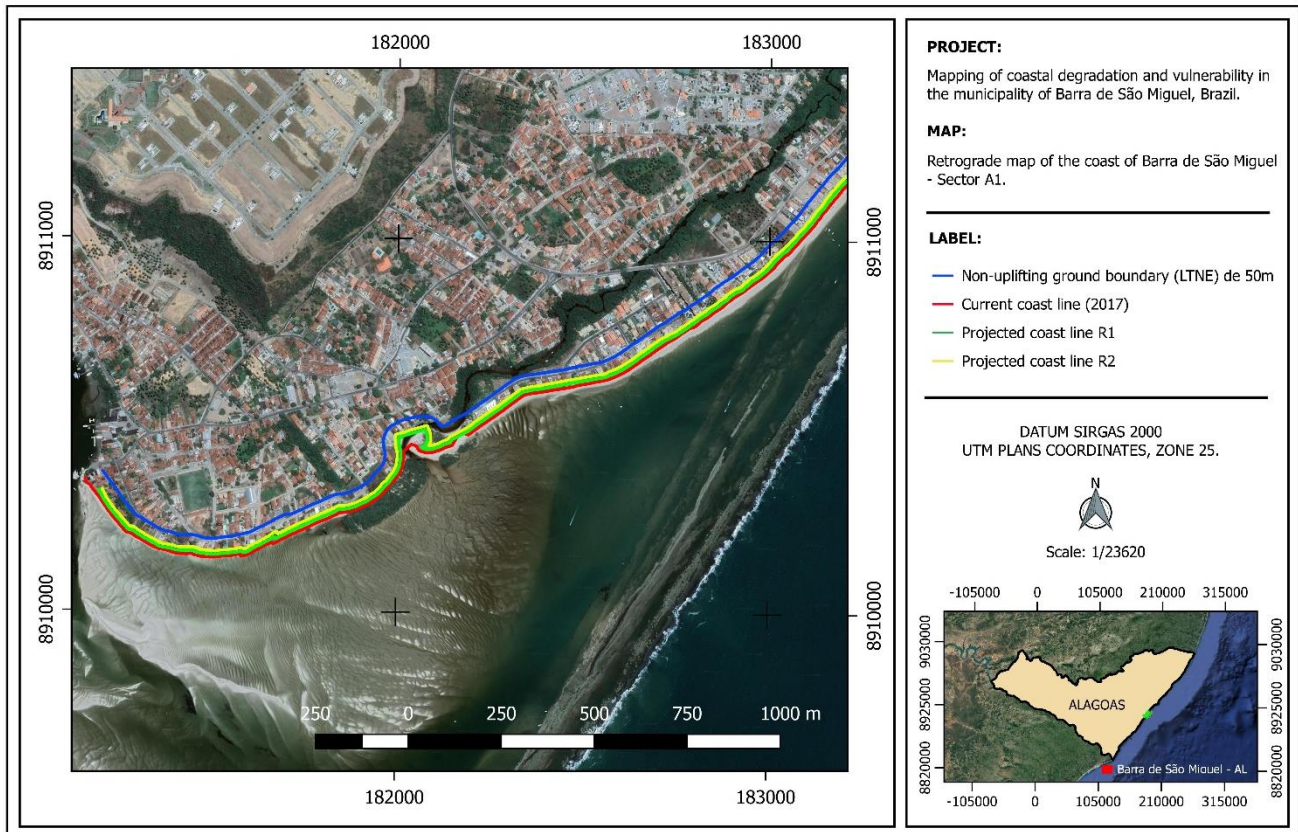

Figure 4 – Map of retrogradation of Barra de São Miguel coast – Sub-section A_1. Source: Author.

Presenting a coastal feature classified as sandy beach, the region will exhibit erosive process in most its extension, except for low mangrove areas that will flood. Regarding vulnerability, we can classify as high due to reduced width of the beach, high waterproofing coastal ridges levels through disorderly urbanization, and post-beach protection buildings (Figure 5).

Figure 5 – High vulnerability area: concrete-faced rockfill beach dams for waves overtopping; High post-beach urbanization; and absence of beach during high tide. Source: Author.

Delimitation of a coastal building zone limit (CBZL), in other words, a minimum protection and landscape esthetic maintenance zone, was established from distances between high water line towards the continent, indicating that the subsection is inserted in a region characterized by urbanized seafront, lagoons and coastal lagoons, and estuaries, thus, a coastal building zone limit of 50 m must be established from the beach border or from the base of the back of the foredune, when existent, towards the continent; and in the flood areas, through a contour line located at least 1 m above the area limit currently reached by syzygy's high-tide.

By relating the optimistic scenario of retrogradation (R_1) to the coastal building zone limit, 74.46% of the building region will be impacted by the sea level rise, demonstrating coherence of legislation in demanding delimitation of coastal protection areas.

However, considering a pessimist scenario of retrogradation (R_2), the value stipulated by law (coastal building zone limit of 50 m) would not be enough to guarantee beach and post-beach preservation, because the affected area would overcome the building limit in approximately 26.88 m inside the continent.

4.2 Subsection A_2

It is limited by plane UTM coordinates (8.911.139 mN, 183.198 mE) and (8.912.353 mN, 184.056 mE), DATUM SIRGAS 2000, with approximate extension of 1.5 km.

Considering sea level rise scenario (S_1 e S_2), estimated, respectively, as more optimistic and more pessimist, A_2 indicated retrogradation R_1 of 8.5 m and R_2 of 17.73 m. Retreats extension, even in the most likely scenario (optimistic), already reached existing buildings in the post-beach region (Figure 6), although, with
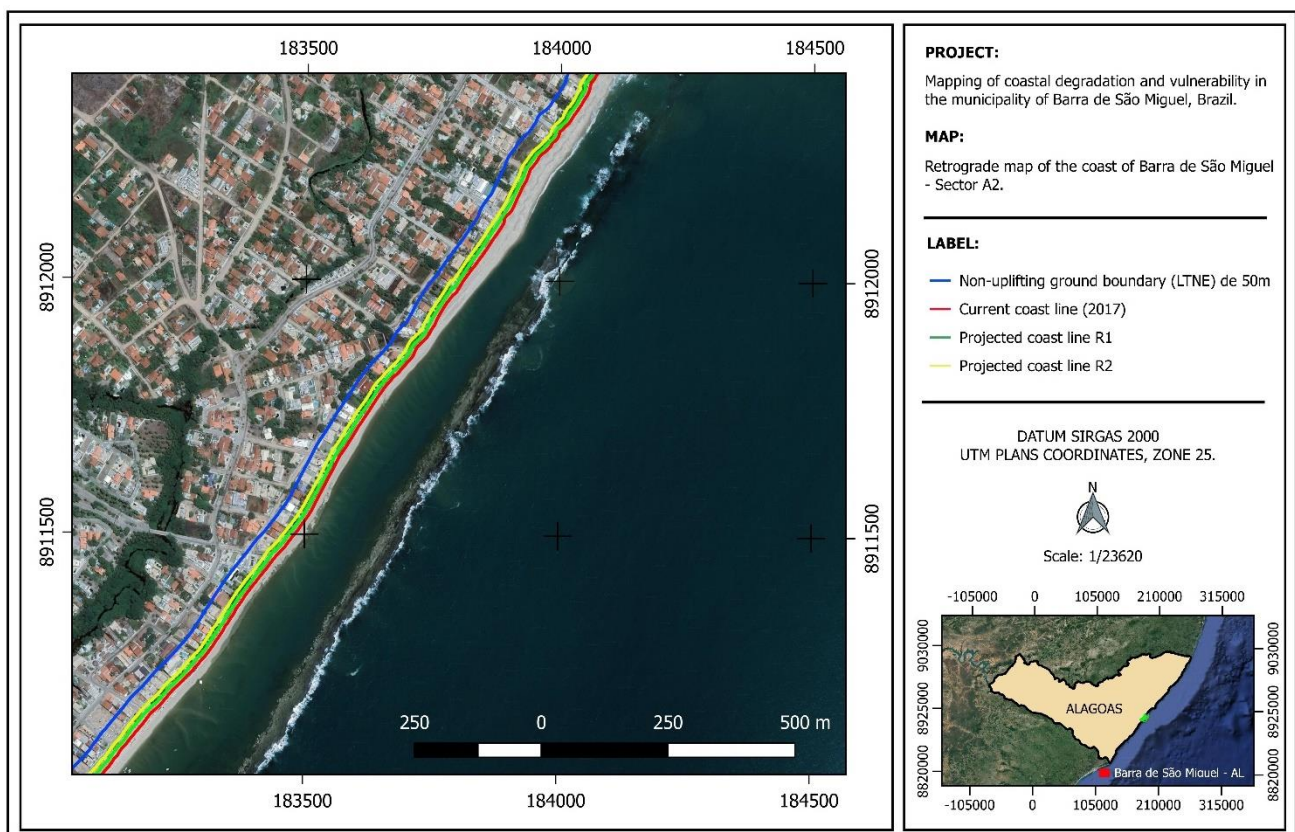
less amplitude compared to the effects of sea level rise over subsection A_1.

Figure 6 – Map of retrogradation of Barra de São Miguel coast – Subsection A_2. Source: Author.

According to Nicholls et al. (1995), this coast piece will present erosive process in most its extension, except for the lower areas of mangrove located throughout Niquim River, which will suffer flood.

Regarding vulnerability, we can classify it as high (predominant) to low vulnerability (in more preserved regions), due to waterproofing level of post-beach area through disorderly urbanization, well-developed

beach and installation of coast ridge containment buildings (Figures 7 and 8).

Figure 7 – Area of High Vulnerability: Containment of the coast ridge by building beach dams; High post-beach urbanization; and Well-developed beach.

Figure 8 – Area of Low Vulnerability: Preserved coast ridges and fixed by restinga vegetation; Moderate post-beach urbanization; and Well-developed beach.

Similarly to subsection A_1, this subsection is inserted in a region characterized by an urbanized beachfront and flood-prone areas, so that the following measures should be applied, respectively, coastal building zone limit of 50 m from the beach border or from the base of the back of the foredune, when existent, towards the continent; and in flood-prone areas, by a contour line located to a quota of at least 1 m above the limit area currently reached by syzygy's high tide.

Associating the optimistic scenario of retrogradation (R_1) to the coastal building limit zone, 16.75% of the building region will be impacted by the sea level rise, corroborating with legislation regarding coastal protection areas delimitation.

4.3 Subsection A₃

It is limited by plane UTM coordinates (8.912.353 mN, 184.056 mE) and (8.913.621 mN, 184.763 mE), DATUM SIRGAS 2000, with approximate extension of 1.5 km.

Prospect of sea level rise (S_1 and S_2) indicate retrogradation R_1 of 11.47 m and R_2 of 23.91m. Evaluating retreats extension, even in the optimistic scenario (S_1), there would be impacts on the buildings of the post-beach region (Figure 9), with flooding in the lower inland areas of mangrove.

Different from subsections A_1 and A_2, low anthropic occupation level was verified within this part of the coast, specifically within the post-beach zone, which represents a reduction of the destructive process of
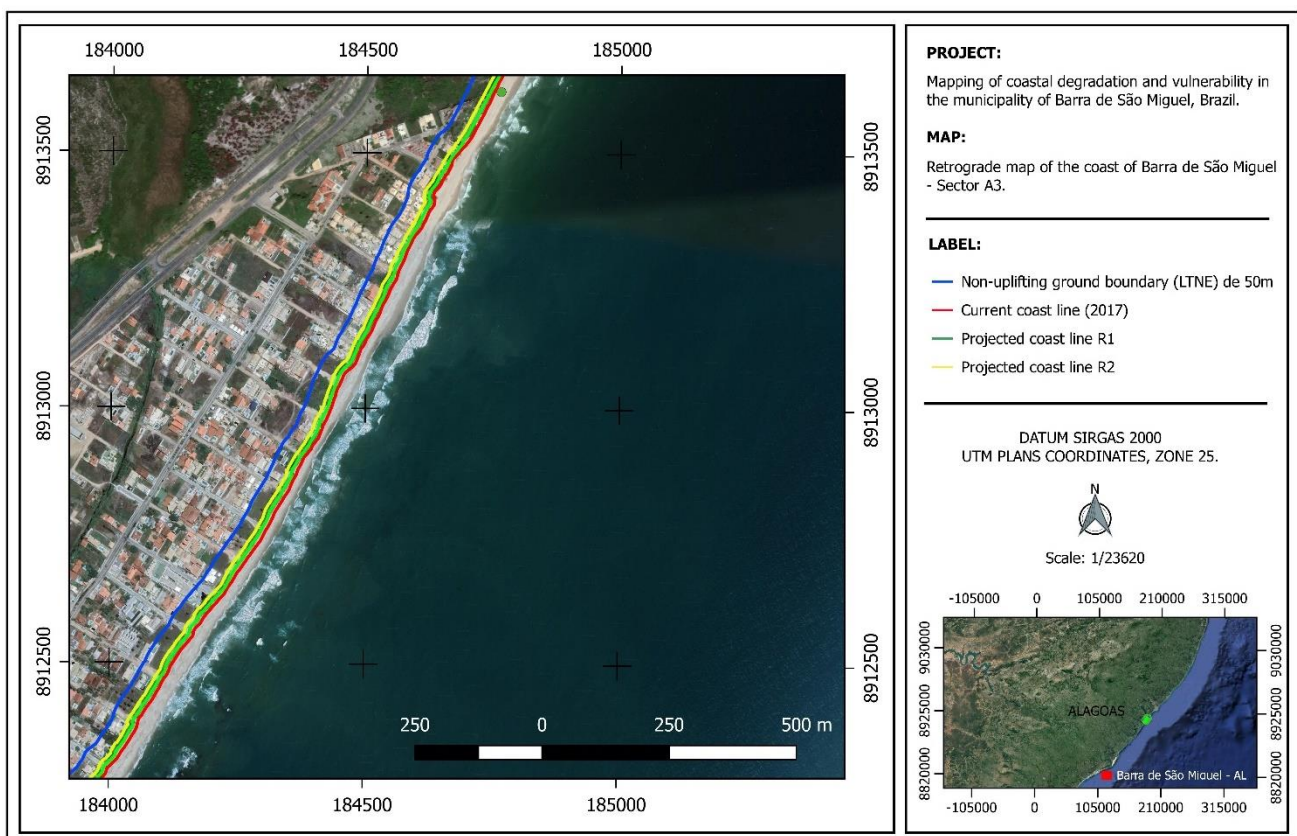
the restinga vegetation, dunes destruction and waterproofing of Holocene marine terraces.

Figure 9 – Map of retrogradation of Barra de São Miguel coast – Subsection A₃. Source: Author.

Regarding vulnerability, it is classified as low (predominant) to high vulnerability, due to waterproofing level of the post-beach area by disorderly urbanization, reduced beach and post-beach containment buildings (Figure 10 [a] and [b]).
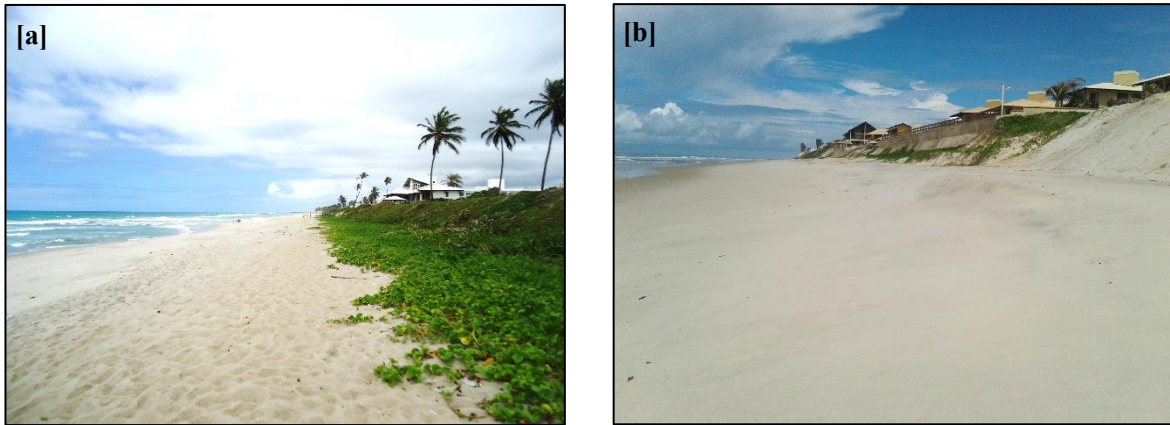
Figure 10 – [a] Area of Low Vulnerability: Preserved coast ridges and fixed by restinga vegetation; Low post-beach urbanization; Well-developed beach. [b] Area of High Vulnerability: Occupied coast ridges and fixed by beach dams; Moderate post-beach urbanization; and Well-developed beach. Source: Author.

Located in a region characterized by an urbanized seafront and flood-prone areas, coastal building zone limit should be established 50 m from the beach border or from the base of the back of the foredune, when existent, by a contour line located from a quota of at least 1 m above the limit area currently reached by the syzygy's high tide.

Regarding coastal regions delimited by the coastal building zone limit, it was possible to verify, when associating this to the retrogradation scenario R_1, that 22.98% of the building zone will be impacted by the sea level rise.

4.4 Section B

It is spatially limited by plane UTM coordinates (8.913.621 mN, 184.763 mE) and (8.916.590 mN, 186.626 mE), with approximate extension of 3.5 km.

Considering sea level rise scenarios (S_1 and S_2), prospects indicate retrogradation R_1 of 15.1 m and R_2 of 31.45 m. Evaluating extension of retreats, buildings would not be impacted in both scenarios, due to the absence of significant anthropic disturbances within this coast piece (Figure 11).
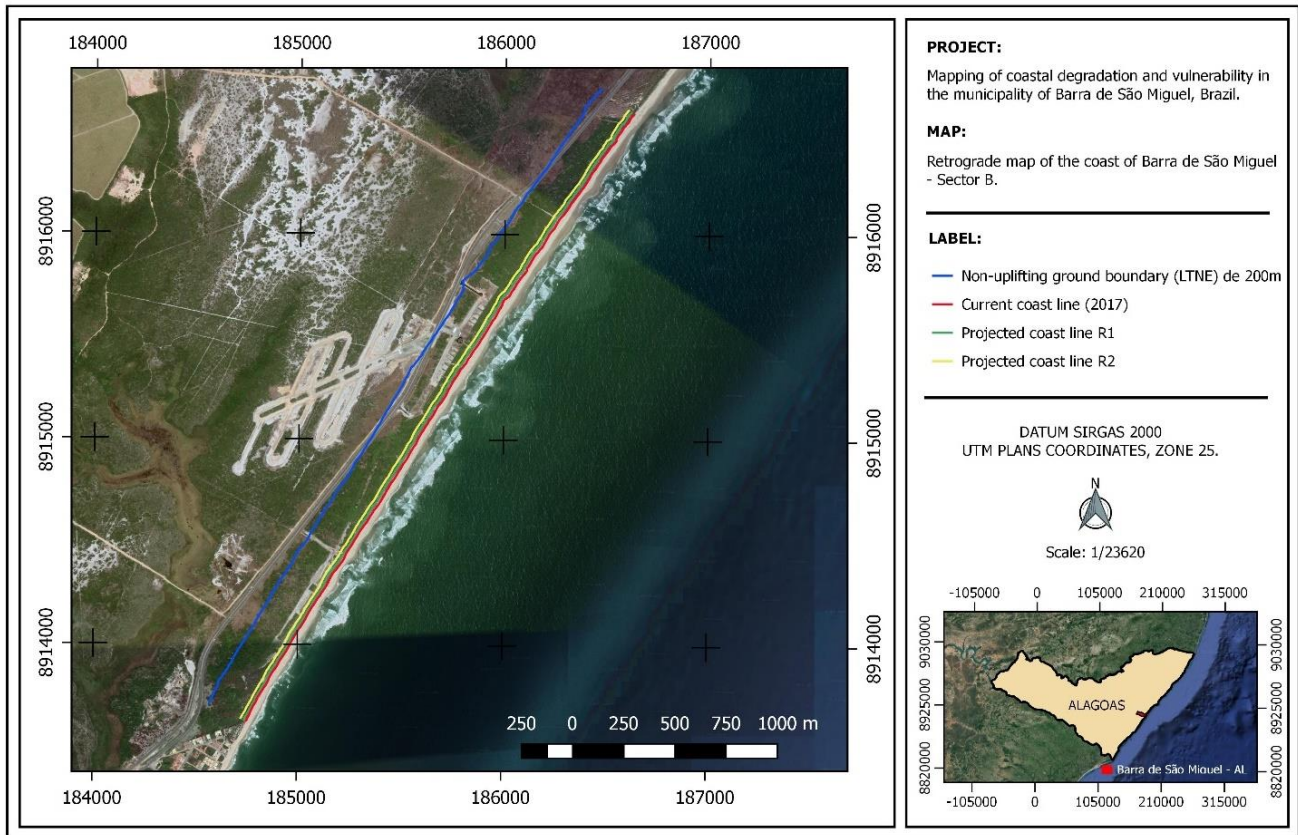

Figure 11 – Map of retrogradation of Barra de São Miguel coast – Section B. Source: Author.

This subsection is located in a region characterized by non-urbanized seafront, thus, coastal building zone limit of 200 m should be established from the beach border or the base of the back of the foredune, when existent, towards the continent.

Thus, evaluating retrogradation R_1 impact over the area defined by the coastal building zone limit, it was possible to verify that 7.46% of the building region will be impacted by the sea level rise.

This section is classified as low vulnerability area, due to the presence of well-developed beach compartmentalization and with all sub-environments (post-beach, beach and fore-beach) preserved (Figure 12 [a] and [b]).

Figure 12: [a] Area with Low Vulnerability: Coastal ridges fixed by restinga vegetation; and well-developed beach. [b] Absence of post-beach urbanization; Preserved Holocene marine terrace and fixed by restinga vegetation. Source: Author.

Lastly, considering optimistic retreats (R_1) defined by Brunn Law (1992); the response of different types of coastal features to a sea level rise (Nicholls *et al.*, 1995); and definition of coastal building zone limit (Muehe, 2001), it was possible to establish a synthesis of retrogradation for sections A and B, observed on table 2:

Table 2 - Projection of retrogradation and vulnerability for sections A and B.

Section	Sub Section	Retreat of Coast Line (RCL)		Coastal Building Zone Limit (CBZL)		[1] Impact Level (%)	[2] Predominant Risk Factor to Erosion
		Optimistc Extension (m)	Area (m²)	Extension (m)	Area (m²)		
A	A_1	36.88	91,645.73	50	123,078.70	74.46	3
	A_2	8.50	12,618.36	50	75,330.70	16.75	3
	A_3	11.47	16,865.27	50	73,383.11	22.98	1
B	-	15.10	53,446.49	200	716,564.53	7.46	1

[1]Representative value of impact level over the area delimited by the coastal building zone limit, considering retrogradation established by the optimistic scenario of the SLR, [2]Erosion risk (Dal Cin & Simeoni, 1994): 1 – Low vulnerability, 2 – Moderate Vulnerability and 3 – High vulnerability.

5. FINAL CONSIDERATIONS

Regarding categorization of the vulnerability level of the coast to marine erosion, it is possible to conclude that approximately 57% of the coast in the study area (section A) is threatened by the RSL rise, presenting high vulnerability rate. In contrast, section B, due to the presence of well-developed beach, without containment buildings, absence of anthropic occupation and preserved restinga vegetation, it was diagnosed with low vulnerability potential to erosion.

It was also verified that retrogradation prognosis of the coastline, based on scenarios predicted by the IPCC, indicated that even in an optimistic scenario, retreats (R_1) over the coast of the study area are increased, reaching all buildings in the section A, from 8.5 m inland subsection A_2; 11.47 m inland sub-section A_3; and until 36.88 m inland sub-section A_1. Section B, despite presenting high environmental preservation level, would exhibit retreat of 15.1 m.

Determination of the coastal building zone limit, in other words, a minimum zone for the protection and esthetic maintenance of the landscape, established from distances between the current high tide line towards the continent, demonstrated that previous adoption of coastal building zone limit results throughout the sections would be enough to absorb future impacts originated from sea level rise over the coast in the study

area. Thus, a fundamental aspect for coastal building zone limit fixation beyond the optimistic scenario of retrogradation is the definition of the evolutionary trend of the coast, both on a geological time scale (hundreds to thousands of years) and on the time scale of the current process (years and decades).

Regarding the perception of coastal erosion throughout the beaches, it was concluded that urbanized regions presented erosive processes in almost its entire extension, due to the intense waterproofing of the post-beach through the construction of summer houses, beach dams and bagwall-like structures, besides, the absence of beaches nearby São Miguel and Niquim rivers mouths. Thus, it can be concluded that the combination of these factors intensified the erosive process in the region, although, it is not more visible due to permanent anthropic actuation in order to contain sea rise.

Thus, it is valid to affirm that results obtained by this study are important to comprehend coastal environment of Barra de São Miguel County, and it can be used as a guiding source in coastal monitoring and management of the region. Observations should be expanded through complementary studies within time spaces of years and decades, in order to obtain spatial/temporary morphodynamic parameters to define evolutionary trends of the county.

6. REFERENCES

[1] [Anonymous 2018] Details omitted for double-blind reviewing.

[2] ASSIS, H. M. B. Influência da hidrodinâmica das ondas no zoneamento litorâneo e na faixa costeira emersa, entre Olinda e Porto de Galinhas, Pernambuco. 2007. 140 f. Tese, Doutorado em Geociências, Programa de Pós-Graduação em Geociências, Universidade Federal de Pernambuco, 2007.

[3] ARAÚJO, T. M.; SANTOS, R. C. A. L.; SEOANE, J. C. S.; MANSO, V. A. Erosão e Progradação do Litoral Brasileiro, Alagoas. In: MUEHE, D. Erosão e progradação no litoral brasileiro. Brasília: Ministério do Meio Ambiente, 2006.

[4] BRUUN, P. Coast erosion and the development of beach profiles. Washington: Beach Erosion Board, 1954.

[5] BRUUN, P. Sea-level rise as a cause of shore erosion. Journal of the Waterways and Harbors division, [s.i.], v. 88, n. 1, p. 117-132, 1962.

[6] COUTINHO, P.N. Geologia marinha da plataforma continental Alagoas-Sergipe. Recife. 1976. 119 f. Tese, Livre Docência, Universidade Federal de Pernambuco. 1976.

[7] DAL CIN, R.; SIMEONI, U. A model for determining the classification, vulnerability and risk in the southern coastal zone of the Marche (Italy). Journal of Coastal Research, [s.i.], v. 10, n. 01, p. 18-29, 1994.

[8] DEAN, R. G. Equilibrium beach profiles: characteristics and applications. Journal of coastal research, [s.i.], v. 07, n. 01, p. 53-84, 1991.

[9] DOMINGUEZ, J. M. L. Regional assessment of short and long term trends of coastal erosion in northeastern Brazil. Land-Ocean Interactions in the Coastal Zone, São Paulo, p. 8-10, 1995.

[10] GRUBER, N. L. S. A antepraia na região de Tramandaí - RS. 2002. 207 f. Tese, Doutorado em Geociências, Programa de Pós-Graduação em Geociências, Universidade Federal do Rio Grande do Sul, Porto Alegre, 2002.

[101 HALLERMEIER, Robert J. A profile zonation for seasonal sand beaches from wave climate. Coastal Engineering, v. 4, p. 253-277, 1980-1981.

[12] MANSO, V. A. V.; COUTINHO, P. N; LIMA, A. T. O; MEDEIROS, A. B.; BORBA, A. L. S.; LIRA, A. R. A.; PEDROSA, F. J. A.; MARTINS, M. H. A.; CHAVES N. S.; DUARTE, R. X.; ALMEIDA, L. E. S. B.; TOLDO JR. E. E. & IVO, P. S., 1995. Estudo da erosão marinha na praia da Boa Viagem. In: CONVÊNIO EMLURB/FADE/LGGM-UFPE. Relatório Final. Recife. 106 p.

[13] MANSO, V. A. V.; MACEDO, R. J. A. ; SILVA, E. R. M. E. ; PEREIRA, N. S. ; SOARES JUNIOR, C. F. A. ; ARRAES, M. ; ALVES, F. P. . Subsídios ao Gerenciamento Costeiro: Definição da Zona Não Edificante da Praia do Porto (PE) para uso e Ocupação da Orla. In: ESTUDOS GEOLÓGICOS (UFPE), v. 22, p. 21-36, 2012.

[14] MUEHE, D. Critérios morfodinâmicos para o estabelecimento de limites da orla costeira para fins de gerenciamento. Revista Brasileira de Geomorfologia, Brasília, v. 2, n. 1, p. 35-44, 2001.

[15] MUEHE, D. Definição de limites e tipologias da orla sob os aspectos morfodinâmico e evolutivo. In: MINISTÉRIO DO MEIO AMBIETE (MMA); MINISTÉRIO DO PLANEJAMENTO, ORÇAMENTO E GESTÃO (MPO). Projeto de Gestão Integrada da Orla Marítima (Projeto Orla): subsídios para um projeto de gestão. Brasília: MMA, 2004, p. 13-32.

[16] NICHOLLS, R. J.; LEATHERMAN, S. P., DENNIS, K. C. E VOLONTÉ, C. R. Impacts and responses to sea-level rise: qualitative and quantitative assessments. Journal of Coastal Research, [s.i.], v. 14, p. 26-43, 1995.

[17] LINS-DE-BARROS, F. M. Erosão costeira e gerenciamento: estudo de caso do litoral de Maricá, Rio de Janeiro. In: Seminário Maricá Dinâmica Urbana e Ambiental, 1., Maricá/RJ. Anais. Maricá/RJ: [s.i.], 2005, p. 03-23.

[18] PILKEY, O. H., YOUNG, R. S., RIGGS, S. R., SMITH, A. W. S., WU, H., PILKEY, W. D.The concept of shoreface profile of equilibrium: a critical review. Journal of Coastal Research, [s.i.], v. 9, n. 1, p. 255-278, 1993.

[19] SANTOS, R. C. A. L. Evolução da linha de costa à médio e curto prazo associada ao grau de desenvolvimento urbano e aos aspectos geoambientais na planície costeira de Maceió – Alagoas. 2004. 176 f. Tese, Doutorado em Geociências, Programa de Pós-Graduação em Geociências, Universidade Federal de Pernambuco, Recife, 2004.

[20] SCHWARTZ, M. L., 1967. The BRUUN theory of sea-level rise as a cause of shore erosion. Journal of Geology, [s.i.], v. 75, p. 76-92, 1967.

[21] SILVA, J. S .V.; SANTOS, R. F. Zoneamento para planejamento ambiental: vantagens e restrições de métodos e técnicas. Cadernos de Ciência & Tecnologia, Brasília, v. 21, n. 2, p. 221-263, p, 2004.

[22] WONG, P. P.; LOSADA, I. J.; GATTUSO, J. P.; HINKEL, J.; KHATTABI, A.; MCINNES, K. L.; SAITO, Y.; SALLENGER, A. Coastal systems and Low-Lying Areas. In: FIELD, C. B.; BARROS, D. J.; DOKKEN, K. J.; MACH, M. D.; MASTRANDREA, T. E.; BILIR, M.; CHATTERJEE, K.L.; EBI, Y. O.; ESTRADA, R. C.; GENOVA, B.; GIRMA, E. S.; KISSEL, A. N.; LEVY, A. N.; MACCRACKEN, S..; MASTRANDREA, P. R.; WHITE, L. L. (Eds.). Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panelon Climate Change. Cambridge: Cambridge University Press, 2014, p. 361-409.