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Proposal for improvement of methodology to determine the potential of economic losses due to coastal erosion

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ABSTRACT

Erosion is a phenomenon that can promote the retreat of the shoreline in various regions in the world. Currently, perceived the damage caused by this phenomenon in the economy, the environment and the society. With this, methodologies emerged to determine coastal erosion rates. These methodologies have evolved and today it is possible to determine implications of coastal erosion in other economic activities, such as tourism, for example. Another technique was designed to determine the potential of economic damage due to coastal erosion. this methodology, however, presents limitation for determining the long-term erosion behavior. Thus, the objective of this paper was to overcome this limitation, in order to improve the methodology that defines the potential of economic damage due to coastal erosion. It was found in this paper that the multi-temporal analysis of products of remote sensing allows to overcome this limitation. For the evaluation and discussion, the Municipality of Areia Branca (RN, Brazil) was chosen, where the potential for economic damage to coastal erosion observed was of medium intensity. Methodologies that assess coastal erosion and its potential for economic damage should be continuously conceived and improved in order to better understand the erosive process and its economic implications.

Keywords: geoprocessing; susceptibility to economic damages; coastal management.

Proposta de aperfeiçoamento de metodologia para determinação do potencial de prejuízos econômicos face à erosão costeira

RESUMO

A erosão é um fenômeno que pode promover o recuo da linha de costa em várias regiões no mundo. Atualmente, percebem-se os danos provocados por esse fenômeno na economia, no meio ambiente e na sociedade. Assim, metodologias surgiram para determinar as taxas de erosão costeira. Essas metodologias evoluíram e hoje é possível determinar implicações da erosão costeira em outras atividades econômicas, como no turismo, por exemplo. Outra técnica foi concebida para a determinação do potencial de danos econômicos face à erosão costeira. Essa metodologia, contudo, apresenta limitação para a determinação do comportamento da erosão em longo prazo. Assim, o objetivo do presente estudo foi o de superar essa limitação, de modo a aperfeiçoar a metodologia que define o potencial de prejuízos econômicos face à erosão costeira. Foi constatado no presente artigo que a análise multitemporal permite superar essa limitação. Para a avaliação e discussão, foi escolhido o Município de Areia Branca (RN), onde o potencial de danos econômicos face à erosão costeira constatado foi de média intensidade. As metodologias que avaliam a erosão costeira e

o seu potencial de prejuízos econômicos devem ser continuamente concebidas e aperfeiçoadas no intuito de melhor compreender o processo erosivo e suas implicações econômicas.

Palavras-chave: geoprocessamento; susceptibilidade a danos econômicos; gerenciamento costeiro.

Introduction

One of the modeling agents of the coastal zone is the erosion process (Fairbridge, 2004), which displaces the shoreline whether it is due to natural or by man-made reasons (Camfield and Morang, 1996). Initially, due attention was not paid to process of shoreline erosion until the moment when adverse effects were felt on the economy, society and the environment (Silva et al., 2014), an example, are the damage caused by erosion in infrastructure used by the tourism industry (Alexandrakis et al., 2015).

In view of this, the quantification of the process of shoreline erosion is relevant to coastal zone planners and managers for many reasons, and one of them is to study the effectiveness of protection structures that reduce the action of this process. The techniques that make this quantification evolved since the 1970s, mainly the result of the advancement of technology (Moore, 2000). A demonstration of this evolution is perceived by the equipment and products used by the old methodological procedures, such as that conceived by Dolan et al. (1978), which used monochrome aerial photographs and light table designed to determine erosion rates, different from the methodologies that have emerged later, which can use sophisticated remote sensing products (airborne light detection and ranging technology - LIDAR, multispectral imaging, microwaves sensors and video imaging (Boak and Turner, 2005), unmanned aerial vehicle - VANT (Mancini et al., 2013), in conjunction with geographic information systems (Ojeda Zújar et al., 2013).

The advances are also observed with the design of methodologies that relate the effects of coastal erosion in other sectors such as the tourism activity (Alexandrakis et al., 2015). Another methodology that aims to make a connection between the shoreline erosion and its implications in other human activities, is the one that determines the potential for economic damage due to of the action of this process (Santos et al., 2007). This methodology proposed by Santos et al. (2007) consists of a preliminary analysis that indicates the susceptibility of coastal stretches to the economic damage resulting from erosive processes of the shoreline.

In this methodology, the potential for economic damage is determined based on the susceptibility erosion and the density of

urbanization. To determine the erosion susceptibility, the authors made use of geoindicators in the field such as roots of exposed trees, fallen trees, presence of active cliffs, destroyed urban equipment, among others (Santos et al., 2007). The use of these geoindicators is relevant, however, it is not possible to determine whether the progradation or retrogradation behavior is short or long-term.

In order to consider this limitation, the use of the methodology developed by Grigio et al. (2005), was proposed to determine the susceptibility of erosion, given the practicality, low cost of its use, ease, efficiency and, mainly, because it can determine whether the trends in action of accretion or erosion processes are short or long-term, depending only on the availability of remote sensing products to the location in study. In view of the above, the aim of this paper is to contribute to the improvement of the methodology that assesses the potential for economic damage due to shoreline erosion, in particular, to overcome the limitation of the establishment of behavior trends in the shoreline in the long-term. Thus, this research contributes both to scientific bias, which consists of improving a methodology, as well as by social bias, which subsidizes with information the planners and managers of the coastal zone.

Material and methods

Characterization of the area of study

The Municipality of Areia Branca is located in the northern coast of Rio Grande do Norte (Figure 1) at a distance of 330 km from Natal, capital of the State. As socioeconomic characteristics are the production of salt of marine origin (Costa et al., 2013), exploitation of oil, wind power generation, tourism (Medeiros et al., 2012), agriculture and occupation, near the shoreline, by traditional fishermen. Therefore, the municipality of Areia Branca has a variety of activities of land use and occupation.

In geological terms, this municipality is inserted in the geological context of the Potiguar Basin (Araripe and Feijó, 1994; Pessoa Neto et al., 2007). On or near the shoreline are observed following geological features: beach rocks; alluvial deposits; deposits of fixed dunes; mobile dune

wind deposits; tidal plains deposits and the barrier formation. Already, the geomorphological features are as follows: fixed and mobile dune fields; fluvial-estuarine floodplain; tide plain; longitudinal bars emerged at low tide and intertidal zone (Rogerio, 2004).

In the coastal area of Areia Branca the predominant direction of the wind is northeast, where in summer the maximum and minimum

speeds are: 34.4 km/h and 27.5 km/h, respectively, already in the winter period the monthly average is 21.1 km/h. The flow of waves is northeast direction with heights ranging from 0.22 m to 0.39 m. Already, marine currents vary in winter and summer periods, the speed in the first is 0.6-1.3 m/s to the west, and in the second, 0,2-0,6 m/s to the west (Rogerio, 2004).

Figure 1. Location of the study area, coastal area of the municipality of Areia Branca, Rio Grande do Norte, Brazil.

Methodological procedures

To determine the potential for economic damage to shoreline erosion, it is necessary first to establish the sensitivity to erosion of the shoreline and, also, the density of urbanization.

Thus, to establish the sensitivity of erosion, the multitemporal analysis of the shoreline was performed, through remote sensing data and geographic information system. Remote sensing products consisted of the following scenes: Landsat 5-TM 215-64 (Instituto Nacional de Pesquisas Espaciais [INPE], 1984) and Landsat 8 OLI 215-64 (United States Geological Survey [USGS], 2016). The images were acquired from the electronic sites from the National Institute for Space Research – INPE (Brazil) and the United States Geological Survey - USGS.

Analysis of the variation of the shoreline comprised a of 32-years (1984-2016) time space. Unlike other studies (Grigio et al., 2005; Amaro et al., 2014), this period was not divided into other minors, the absence of coastal work that modified

the sediment budget. The use of only two dates to determine erosion and accretion rates is an useful and simple technique, especially when there were no substantial changes of anthropic origin, as in the case of Areia Branca (RN, Brazil), these changes can be, for example, the construction of dikes or ports that interfere with the sediment budget of the shoreline (Ojeda Zújar, 2000).

To use the Landsat 5 image it was necessary to perform its georeferencing. After the images are in the same coordinate system (SIRGAS 2000 UTM 24 South) a base/reference polygon was established, which has the limits of the area of interest, used in the cutting of images (Figure 2). The next phase consisted of digital processing of image (Grigio et al., 2005).

The processing of images consisted of the following procedures: the spectral bands of green and infrared underwent linear contrast enhancement, then, the ration of these bands was performed using the NDWI (Normalized Different Water Index) algorithm that has the following Green - Near Infrared / Green + Near Infrared

ration (McFeeters, 1996), the result of this algorithm was again applied to the linear contrast highlight. Finally, the composition RGB-Infrared-

Green-NDWI (Figure 3) is formed (Grigio et al., 2005). These procedures were carried out for Landsat 5 and Landsat 8 images.

Figure 2. Base polygon delimiting area of interest for cutting layers.

Figure 3. Colorful composition RGB-4-2-NDWI of Landsat 5 (1984).

The composition mentioned above makes it possible to distinguish the shoreline that uses as reference the response of the sand and the oceanic waters: dry sand has yellowish tones, while it is moist, have bluish yellow tones, ocean waters range from vary navy blue and indigo blue (Grigio et al., 2005).

After the images having been cut it was held the vectoring of coast line for the years 1984 and 2016. Following, the two shorelines are overlapped. From this crossing is generated a table with two columns (Table 1). The first corresponds to 1984 and the second to the 2016. The values in the table have the following meaning: when in the first column have the value zero and in the second negative one (-1) the actuating process was erosion, while the inverse is the accretion process,

the record of zero in the two columns is because no modification occurred, i.e., balance situation (Grigio et al., 2005). Based on these criteria, a column is introduced containing the final result (Table 1).

Table 1. Table produced by the union between 1984 and 2016.

1984	2016	Classification
0	-1	Erosion
-1	0	Accretion
0	0	Balance

In order to have the punctual quantitative detailing of the action of the performance of erosion and accretion processes, a second

vectorization is performed. This has the following criteria: the polygon area must be equal to or greater than 900 m² due to the spatial resolution of 30 m of images under analysis. Probably, the result of this second vectorization will a small change when compared to the first (Grigio et al., 2005).

The result of the crossing of 1984 and 2016 made it possible to determine which processes were most active along the shoreline. For the classification of susceptibility of the shoreline, the following characteristics were observed: stretches with a tendency to progradation (low susceptibility); stretches in equilibrium (average susceptibility); stretches located near to river mouths (high sensitivity) and stretches in erosion (very high susceptibility). For low, medium, high and very high values, indices 1, 2, 3 and 4, respectively, that are used to determine the potential damage (Silva et al., 2007).

A stretch of land with a width of 50 m, from the shoreline towards the continent, was used to determine the densities of urbanization of the coast. Urbanization densities were defined in three categories using the number of fixed constructions per kilometer of extension along the shoreline: (a) low level, has less than 4 constructions; (b) medium level, between 5 and 10; (c) high level, has more than 10 constructions. The values assigned to the levels: low, medium and high, were, respectively, 1, 2 and 3. This criterion did not consider the beach kiosks constructed with leaves of coconut palms and wood, considering the fragility and the ease with which these constructions are removed (Santos et al., 2007). The stretches were defined based on field work that consisted of walking, some sectors, the 37 km of beaches and viewing with the help of Google Earth (Google, 2016).

Finally, the potential for economic damage due to coastal erosion is determined. This last indicator is the result of the product of the values attributed to the susceptibility of erosion and urbanization densities. The result of this product is thus classified: low (1 to 3), Medium (4 to 8) and high (9 to 12) (Silva et al., 2007).

All phases of digital image processing mentioned, georeferencing, linear contrast enhancement and color composition were performed in SPIRNG 5.3 software (INPE, 2015). On the other hand, the vectorization and intersection of the shorelines were performed in ArcGis 10.1 (Environmental Systems Research Institute [ESRI], 2011).

Results

For the period considered erosion prevailed over accretion (Figure 4) and was significant on some beaches: Upanema, Barra de Upanema, Baixa Grande, Redonda, São Cristóvão and Ponta do Mel. Furthermore, erosion acted smaller in stretches of Pontal, Meio and Morro Pintado Beaches.

In Figure 4 the letters correspond to sections where erosion and/or accretion processes were more active. At the Point **A**, the stretch that corresponds to Pontal Beach, erosion and accretion processes acted by modifying its shape to a more “flattened” shape. The current shape is the result of a retreat that reached 162 meters. Both the Southwest and the West of this point, accretion acted with maximum values of 275 m and 86 m, respectively, in these two places.

At the point **B**, a stretch comprises the Meio Beach, stands out due to being the stretch where erosion and accretion processes were less intense: 41 m of accretion and 60 m of erosion. These data explain a possible dynamic equilibrium between retrogradation and the progradation during the period of this study.

In the extent that the Upanema Beach, point **C**, the action of erosion and accretion processes is observed. The progradation reached 116 m, where it was also noticeable the growth of a sandy sediments bar between this beach and the Meio Beach. Already, the retrogradation, in some stretches, reached 152 m east of Upanema Beach.

The stretch corresponds to Barra de Upanema Beach (point **D**) is characterized by shoreline erosion intense. At one point, a retreat of up to 124 m is recorded, however, the most significant change was in the sandy sediments bar where there is a decrease in its size of up to 388 m. Thus, the community of Paraíso, located in Barra de Upanema (Figure 5) is threatened with the action of this process.

The point **E**, a stretch comprises Baixa Grande Beach, is characterized by the predominance of the erosion process over the accretion along the shoreline. The first process reduced the shoreline reaching a maximum value of 147 m. Already, the second process acted more between this beach and the Upanema beach where the advance towards the sea was, at most, 190 m.

At the point **F**, stretch belonging to Redonda Beach, erosion and accretion acted by modifying the position of the shoreline. The erosion was more active on the east side of this beach, the maximum retreat is 116 m, there is also the disappearance of a sandy bar on the west part.

In an area of the west part of Redonda Beach occurred the action of the accretion process

(maximum of 78 m), however, the progradation was lower when compared with retrogradation.

Figure 4. Result of the intersection of the shorelines of 1984 and 2016 where it is possible to see the sites the erosion or accretion.

Figure 5. Property threatened by the action of the erosive process, Paraíso Community, stretch of Barra de Upanema Beach, Areia Branca (2015).

The stretch belonging to São Cristóvão Beach (point **G**) has a behavior similar to the Redonda Beach, that is, accretion at updrift side and erosion at downdrift side of this beach. The maximum values of progradation and retrogradation were 181 m and 132 m, respectively. The exception to the behavior of accretion at updrift side was the disappearance of a sandy bar.

At the point **H**, a stretch that corresponds to the Ponta do Mel Beach, the erosion process was significant, with a retreat of up to 164 m in the most affected place, situated east of this beach. Already, the accretion, west of this beach, reached a maximum value of 82 m.

In order to compare the data, a second vectorization was performed. Table 2 contains the ledger item, which is the result of the division between the accretion and erosion processes of the two vectorizations. The similarity of the reasons provides a high level of confidence in the results obtained from the two vectorizations (Grigio et al., 2005). Thus, as shown, the level of confidence in the results was high: 0 for the accretion and 0.1 for the erosion.

The total area altered by the accretion and erosion processes was 346.66 ha. Of this total, 113.92 ha (32.9%) of areas progradation and 232.73 ha (67.1%) eroded. Therefore, prevalence of erosion, with 118.81 hectares more than modified area, than accretion, from 1984 to 2016.

When distributed annually, the values corresponding to the accretion and erosion processes, it is possible to obtain the annual rates of the action of these processes. For the period analyzed, the rate of retreat of the shoreline was 7.27 ha/year, already the accretion was 3.56 ha/year. Therefore, a superiority of 3.71 ha/year of the retrogradation over progradation.

Table 2. Comparison of the results of the two vectorizations for the analysis of the shoreline and the reason of their ratio, in hectares.

Process	1984-2016	
	Accretion	Erosion
1st stage	113.92	232.83
2nd stage	113.92	232.73
Ration	0	0.1

After the previous analysis it is possible to determine the sensitivity to erosion of the shoreline. This was framed in three classes: low, high and very high (Figure 6). The first class is 6.9 Km (18.6%), the second 0.8 Km (2.2%) and the third 29.3 Km (79.2%). The very high susceptibility is present in part of the Upanema Beach, on the Baixa Grande Beach, Redonda Beach, São Cristóvão Beach, on its east part and, almost the entire length of the Ponta do Mel Beach.

Figure 6. Different levels of sensitivity to erosion (A), density of urbanization (B) and potential for economic damage (C) of the Areia Branca shoreline, 2016.

As for urbanization density, the following classes were defined: low urbanization density and high urbanization density. The coastal area of the Municipality of Areia Branca has the prevalence of low urbanization density (70%) compared to high urbanization density (30%). This scenario may soon change by growing real estate speculation.

The multiplication of the values attributed to sensitivity to erosion with the level of urbanization results in the potential for economic damage, whose values found were: low potential 7.1 Km (19,2%), average potential 24.2 Km (65,4%) and high potential 5.7 Km (15,4%) (Figure 7).

Figure 7. Percentages of erosion sensitivity, level of urbanization and potential of economic damage along the Areia Branca shoreline, 2016.

This result discriminated 20 coastal segments for the potential for economic damage (Table 3). The beaches that had low economic damage potential are those with: a) low level of urbanization, where there are no fixed constructions near the shoreline or are few, in consonance with a trend towards coastal progradation (segments 2 and 12, located, respectively, at Pontal Beach, and between the Baixa Grande Beach and Morro Pintado Beach), as

well as b) the stretches that have a high level of urbanization and tendency to progradation (segments 3, 5, 7, 13, 15 and 18). These segments are located between the Pontal Beach and Meio Beach (segment 3), between Upanema Beach and Meio Beach (segment 5), Upanema Beach (segment 7), in the Morro Pintado Beach segment (13), in the São Cristóvão Beach (segment 15) and Ponta do Mel Beach (segment 18).

Table 3. Estimate of the potential of economic damage from shoreline erosion to Areia Branca, 2016.

Segment	Sensitivity to erosion	Urbanization level	Potential of economic losses
1	Very high (4)	Low (1)	Medium (4)
2	Low (1)	Low (1)	Low (1)
3	Low (1)	High (3)	Low (3)
4	Very high (4)	High (3)	High (12)
5	Low (1)	High (3)	Low (3)
6	Very high (4)	High (3)	High (12)
7	Low (1)	High (3)	Low (3)
8	Very high (4)	Low (1)	Medium (4)
9	High (3)	High (3)	High (9)
10	Very high (4)	High (3)	High (12)
11	Very high (4)	Low (1)	Medium (4)
12	Low (1)	Low (1)	Low (1)
13	Low (1)	High (3)	Low (3)
14	Very high (4)	Low (1)	Medium (4)
15	Low (1)	High (3)	Low (3)
16	Very high (4)	Low (1)	Medium (4)
17	Very high (4)	High (3)	High (12)
18	Low (1)	High (3)	Low (3)
19	Very high (4)	High (3)	High (12)
20	Very high (4)	Low (1)	Medium (4)

The segments that have medium potential for economic damages are characterized by having a tendency to retrogradation and have a low level of urbanization. The segments that have these characteristics are: 1 (located at Pontal Beach), 8 (Upanema Beach), 11 (Baixa Grande Beach), 14 (comprises part of Morro Pintado Beach, all the length of the Redonda Beach and part of the São Cristóvão Beach), 16 (São Cristóvão Beach and part of Ponta do Mel Beach) and 20 (part of the Ponta do Mel beach). Finally, in segments that have high potential for economic damages there is a trend of retrogradation and has a high density of urbanization. The followings identified with previous characteristics are: 4 (Meio Beach) (Upanema Beach), 9 (Barra de Upanema), 10 (part of Baixa Grande Beach), 17 and 19 (Ponta do Mel beach).

Discussion

At the point **A**, Silva et al. (2015) also observed, for the stretch Pontal Beach, from 1987 to 2014, the prevalence of the erosion process on accretion, where these processes produced a similar form to the current. For point **B**, stretch comprises Meio Beach, the situation of a relative equilibrium, observed in the results, is endorsed by a study, which made an analysis in periods: 1987-1991 (prevalence of accretion); 1991-2001 (prevalence of erosion); 2001-2011 (prevalence of accretion); and, 2011-2014 (prevalence of erosion), therefore, it explains an alternation of supremacy, sometimes accretion and sometimes erosion (Silva et al., 2015). Still in the same study, at point **C**, stretch of Upanema Beach was found the prevalence of the accretion process in two periods (1987-1991 and 1991-2001), erosion stands out in two other periods (2001-2011 and 2011-2014) (Silva et al., 2015). The results of the present paper indicate the continuation of retrogradation in the stretch **C** observed in the previous study.

The stretches **A**, **B** and **C** are located near or at the mouth of the Apodi-Mossoró River. In a multitemporal analysis of the shoreline of this mouth, from 1986 to 2009, maximum erosion and accretion rates of 17 m/year and 17.67 m/year were found, respectively, in addition, the maximum values, in length, of erosion action were 96 m and 100 m accretion (Boori et al., 2010). In a study in the interval of 2003 to 2010, it is possible to visually observe that a passage between the Meio Beach and Upanema Beach has underwent significant changes in relation to the retreat and advance of the shoreline, where the maximum erosion and accretion rates are 313.39 and 80.06

m/year, respectively, to the mouth of the Apodi-Mossoró River (Boori et al., 2012). The results of these authors, for the mouth of the Apodi-Mossoró River, allow to observe that stretches **A**, **B** and **C** are inserted in an area where the action of the erosion and accretion processes are significant.

Besides the Areia Branca town, located near point **A**, suffers from the coastal flood caused by the tides that can be aggravated by sea level rise (Aguir et al., 2018). As an aggravating factor, the ability to adapt to sea level rise is hampered by the high socioeconomic vulnerability of the population of this sector of the state of Rio Grande do Norte (Busman et al., 2017). Paula Junior et al. (2017) evaluated the economic impacts of climate change on salt production in the municipalities of this region, based on the variables wind, evaporation, temperature, sunstroke, precipitation and humidity, which, according to the forecast, will positively impact the salt production, however, they have not taken into account the sea-level rise (Kulp and Strauss, 2019; Hauer et al., 2020) that will flood the regions that today serve for salt production causing damage.

At point **D**, a stretch correspondent to Barra de Upanema, in a periods analysis per, Silva et al. (2015) observed the predominance of the accretion process in the periods 1987-1991 and 1991-2001, while erosion prevailed for the period 2001-2011 and 2011-2014. As observed in the previous study, the continuation of this trend of retrogradation for stretch **D** was observed.

For point **E**, a stretch that covers the Baixa Grande Beach, a trend of retrogradation was also perceived in a 1987-2014 analysis, mainly in the last two periods, 2001-2011 and 2011-2014 (Silva et al., 2015). However, in another study, through surveys of beaches profiles, conducted between April to December 2003, it was found a relative stability of beach morphology, with the exception of July and October characterized by the loss of sediments (Rogerio, 2004). This discrepancy, between the results of the study by Rogerio (2004) and the present study result most likely from the temporal difference and the absence of continuous monitoring of these profiles.

It is noteworthy that, at points **G** and **H**, stretches that correspond to the beaches São Cristóvão and Ponta do Mel, respectively, have structural lineaments, directed by NW-SE, which exercise an important control in the physiography of the shoreline (Maia and Bezerra, 2014).

With regard to the main factors and causes of shoreline erosion in Rio Grande do Norte State, are listed the following: (a) dynamics of coastal circulation, (b) Holocene evolution of coastal

plain, (c) naturally inefficient supply of sediments, (d) construction of rigid structures and (e) tectonic factors (Vital et al., 2006; Vital et al., 2018).

The medium potential (65.4%) economic damage from due to shoreline erosion which prevailed for the Areia Branca (RN, Brazil) was higher than that observed in other studies, for example, at the Costa das Baleias (Bahia – BA, Brazil), prevalence of low potential damage (58.53%) (Santos et al., 2007); at the Costa do Descobrimento (BA, Brazil), low-potential damage supremacy (60%) (Silva et al., 2007); and, at the Costa do Cacau (BA, Brazil), a predominance of low potential for damage (48.78%) (Nascimento et al., 2013).

It is worth remembering that this potential may increase in scenarios of sea level rise, since view, the vulnerability of the Northern coast of Rio Grande do Norte (Muehe, 2010) and mainly because the mouth of the Apodi-Mossoró River is considered of natural risk medium to high, flooding, in the case of this elevation (Diniz et al., 2017). An example of how this sea level rise can interfere in the coastal zone, is the scenario of rising 10 m, of this level, in the region of the mouth of the Apodi-Mossoró River, where an area of 362.81 km² (26.43%), of the total of this mouth would be flooded (Boori et al., 2012). Still, to this mouth, the following percentages were determined for the classes of vulnerability to sea level rise: high, 14.17%, and very high, 8.26%, added to this, the areas to be modified, in scenarios of sea level rise, can vary from 225.2% to 397.4% in the levels of flooding from 1 m and 10 m, respectively (Boori et al., 2010).

To reduce the potential for economic damage due to coastal erosion, it is necessary to implement integrated coastal management (Rangel-Buitrago et al., 2018). This management should be based on an efficient beach erosion monitoring system (Pikelj et al., 2018) using different methods and technologies for this (E.g. Pender et al., 2015; Griffiths et al., 2019; Jayson-Quashigah et al., 2019).

The coastal management can determine a protective range of the coastal zone that should be determined based on the spatial scope of the current morphodynamic process (erosive trend) and sea level rise (Muehe, 2001). Other measures may also be adopted such as: the beach nourishment (Proença et al., 2011; Luo et al., 2016), the construction of groynes (Kristensen et al., 2016), breakwater (Zahra, 2018) and artificial submerged reefs (van Rijn, 2011).

Conclusion

The potential for economic damage caused by coastal erosion in Areia Branca (RN) has been classified as medium and may increase with real estate speculation and the facto construction in the coastal zone that will therefore increase the level of urbanization of this area changing the value of economic damage potential. Another variable that may interfere with this potential is a possible sea level rise that, as a result, may increase eroded stretches.

The use of the methodology developed by Grigio et al. (2005) allowed a better consistency in the determination the sensitivity of shoreline erosion. Thus, the insertion of the methodology aforementioned, within which determines the potential for economic damage (Santos et al., 2007), allows a better accuracy in determination of coastal economic damage due to shoreline erosion by the fact that it determines the character of the behavior of this long-term process. It is noteworthy that the methodology that determines the potential for economic damage consists of a preliminary assessment of these damage, lacking economic data for a more accurate of determination of possible economic damage.

The methodology presented, in line with the improvement proposed here, can be used in all types of coastal environments in the world, in view, the physiographic configuration of the shoreline is not be a factor that prevents the application of this methodology. Thus, this methodology can be considered an important instrument for governments because of the information raised by it being relevant to the planning of coastal occupation. Another important point is the low cost involved in its use since the use of geographic information systems, through free software, together with satellite images free allow its execution, thus allowing its easy application.

There is also the need for conception and continuous improvement of methodologies that aimed to completing the sensitivity of shoreline erosion, as well as to determine the potential for economic damages due to shoreline erosion. There is also a need of improvement in the methodology that determines the density of urbanization.

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