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Evaluation of the effects of a possible sea-level rise in Mangaratiba - RJ

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Abstract

The Intergovernmental Panel on Climate Change estimates that sea-level rise over in the next 100 years will be enough to flood large areas and cause several environmental impacts. The municipality of Mangaratiba (Macroregion of Costa Verde, on the coast of the state of Rio de Janeiro) follows the worldwide trend of population growth in the coastal zone, with large buildings and a very early local commerce in its surroundings. Their beaches are exposed to environmental impacts caused by the relative sea-level rise, which can be intensified mainly by the pressures of anthropic activities. A simulation of the relative sea-level rise in the city of Mangaratiba was carried out, emphasizing the flood areas from the marine transgression. Therefore, with the overlay of the flooded area with the land use map, it was possible to quantify the flood in each one of the classes. Afterwards, through a bibliographical survey and application of interaction and listings matrices, it was possible to evaluate the probable environmental impacts from the flood mentioned above. The result showed that an increase in the relative sea-level in the study area would have several consequences such as coastal erosion, flooding, damage to areas of urban occupation and to the dunes, which could directly affect the infrastructure, housing and local tourism.

Keywords Climate change · Coastal zone · Environmental impact assessment · GIS

Introduction

The Brazilian coastal zone has a length of 8698 km and an approximate area of 514,000 km^2. It comprises natural environments that are located along coasts less than 10 m above sea level (SL) and these are quite sensitive, including as beaches, dunes, coastal plains, barrier islands, lagoons, estuaries, deltas, mangroves, marshes, rocky shores and reefs (Nicolodi and Zamboni 2008).

The Brazilian coastal plains are relatively flat and low-lying, whose formation and evolution resulted from the deposition of marine, estuarine, lagoon and fluvial sediments, closely associated with the variation of the relative sea level (RSL) during the Quaternary period (Suguio et al. 2005; Dillenburg and Hesp 2009; Muehe 2009).

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According to the Brazilian Institute of Geography and Statistics (Instituto Brasileiro de Geografia e Estatística - IBGE), 26.6% of the Brazilian population lives in coastal municipalities, equivalent to 50.7 million inhabitants (IBGE 2011). The coastal municipalities have, on the beach strip, a privileged space for the development of tourist activities, leisure and fishing, among others (Nicolodi and Zamboni 2008).

The elevation process of the world-wide relative sea level (RSL) is caused mainly by the addition of fresh water in the ocean basins (the result of the partial melting of the ice masses stored on the continents) and the thermal expansion of the oceans, one of the consequences of the global temperature increase (e.g. Martin et al. 1996; Cazenave and Llovel 2010; IPCC 2007, 2013).

According to the Intergovernmental Panel on Climate Change (IPCC 2013), ocean thermal expansion and glacier melting were the dominant factors (75% of the increase observed since 1971) in the global sea level rise (SLR) in the twentieth century. Also according to this report, it is estimated that this will result in a rise in RSL of between 0.52 m and 0.98 m by the year 2100.

Some publications provide different estimates for the SLR for the next 100 years: Grinsted et al. (2009) point to between 0.3 and 2.15 m; Vermeer and Rahmstorf (2009) propose a rise of approximately 0.75 to 1.9 m; and Jevrejeva et al. (2010) determined an increase of between 0.6 and 1.60 m. In Brazil, the Pereira Passos Institute (Instituto Pereira Passos - IPP) estimates an elevation of 1.5 m by 2100 in the Rio de Janeiro area (IPP 2008).

Climate change and an accelerated elevation pace of SLR also show their serious effects on the coastal areas of Brazil, including erosion of the oceanic and estuarine coastline (Souza 2010, 2011; Marengo et al. 2017a, b, c). In relation to the state of Rio de Janeiro, the impacts are pointed out in the works of Oliveira et al. (2006), at Restinga da Marambaia - Rio de Janeiro; Ribeiro (2007), in Atafona - São João da Barra; Castro et al. (2011), at the Tartarugas beach - Rio das Ostras; and Passos et al. (2017), in Saco beach - Mangaratiba.

In this context, the present work tested a simulation of future scenarios of the elevation estimates of SLR, on the coast of Rio de Janeiro state, in the segment corresponding to the municipality of Mangaratiba, aiming at the spatialization of areas that could be permanently flooded by the sea and affected by the marine transgression and the possible impacts in relation to the loss of natural and anthropized environments.

Study area

Mangaratiba is one of the municipalities that compose the Macroregion of Costa Verde, on the southern coast of Rio de Janeiro state (Fig. 1). It occupies an area of 347.68 km^2 and presents a very trimmed coastline, being limited to the east by the municipality of Itaguaí, to the north by the municipality of Rio Claro and to the west by Angra dos Reis, being bordered to the south by Sepetiba Bay and the Atlantic Ocean. The municipality has more than 34 sandy beaches.

According to IBGE (2011), the continental edge of Sepetiba Bay in the municipality of Mangaratiba has been the target of intense real estate speculation as a result of disputes between the urban-industrial-port expansion and the tourism and fishing activities, historically associated with the natural heritage. On the other hand, on the ocean's edge of the municipality, Restinga da Marambaia is a very well preserved area.

There is also a trend of population growth. Between 2000 and 2010, the population of Mangaratiba grew at an average rate of 3.89%, therefore being more than double that of the mean Brazilian rate of 1.17% in the same period (the urbanization of the municipality went from 79.76 to 88.11%). In 2010, 36,456 habitants lived in the municipality, according to the latest population census of 2010 (IBGE 2011).

The coastal area of Mangaratiba exhibits physiographic features that depict a great diversity of depositional environments and evolutionary processes. This coastline was classified by Suguio (2003) as a submerged coast, due to the characteristic features of a shallow, heavily shortened coastline, dominated by the reliefs associated with the crystalline basement of the Serra do Mar and narrow coastal plains embedded in small depressions.

The coastal plains are very narrow and are formed by marine-beach, estuarine and fluvial deposits of essentially Holocene age (RADAMBRASIL 1983; Silva 2002). The environments were formed and were affected by the eustatic and climatic oscillations during the upper Quaternary. The coastal physiography of the region was also controlled by neotectonics, reflecting a coast with submersion characteristics.

In the landscape of Mangaratiba, the Restinga de Marambaia stands out, a narrow sandstone (maximum width of 5000 m and minimum of 20 m) 'neck' of land connected to the mainland at Guaratiba Hill, which extends eastwards towards the Telégrafo Stone by Borges (1990, 1998). This formation is marked by the presence of beach ridges and dunes, and was characterized as an area highly vulnerable to climatic variations and passive of intense erosive processes (Bastos and Napoleão 2010).

The local climate is within the macroclimate Aw - Rainy Tropical Climate (Köppen 1948). The region's air temperatures are typical of tropical coastal areas, with monthly averages always above 20.0 °C and the annual average reaches 23.7 °C. The average annual precipitation is 1239.7 mm, with 37% occurring during the summer during the rainy season and 15% during the winter, during the driest season (Mattos 2005).

The prevailing winds in the region are the south / southwest winds direction, being the most frequent ones and of greater speed (Signorini 1980a; Borges 1990). Climatological data (from the weather station on Guaíba Island, at the entrance to Sepetiba Bay) show that the south quadrant winds are more frequent and energetic than the north quadrant (Fragoso 1995).

The currents generated by the density gradients in the region have very reduced velocities, having the tide as their main mechanism of formation. In addition, there is a lag of the tidal wave between the entrance and the bottom of the bay, which generates accentuated elevation gradients of the SLR (Signorini 1980a, b; Fragoso 1995).

Methods

The simulation of the effects caused by the SLR and the further impacts evaluation in the coastal zone through the application of geotechnologies have been widely used in the last decades around the world (e.g. Snoussi et al. 2007; Akumu et al. 2010; Natesan and Parthasarathy 2010; Niang et al. 2010; Torresan et al. 2013; Al-Buloshi et al. 2014). The research methodological development is presented in the flowchart (Fig. 2).

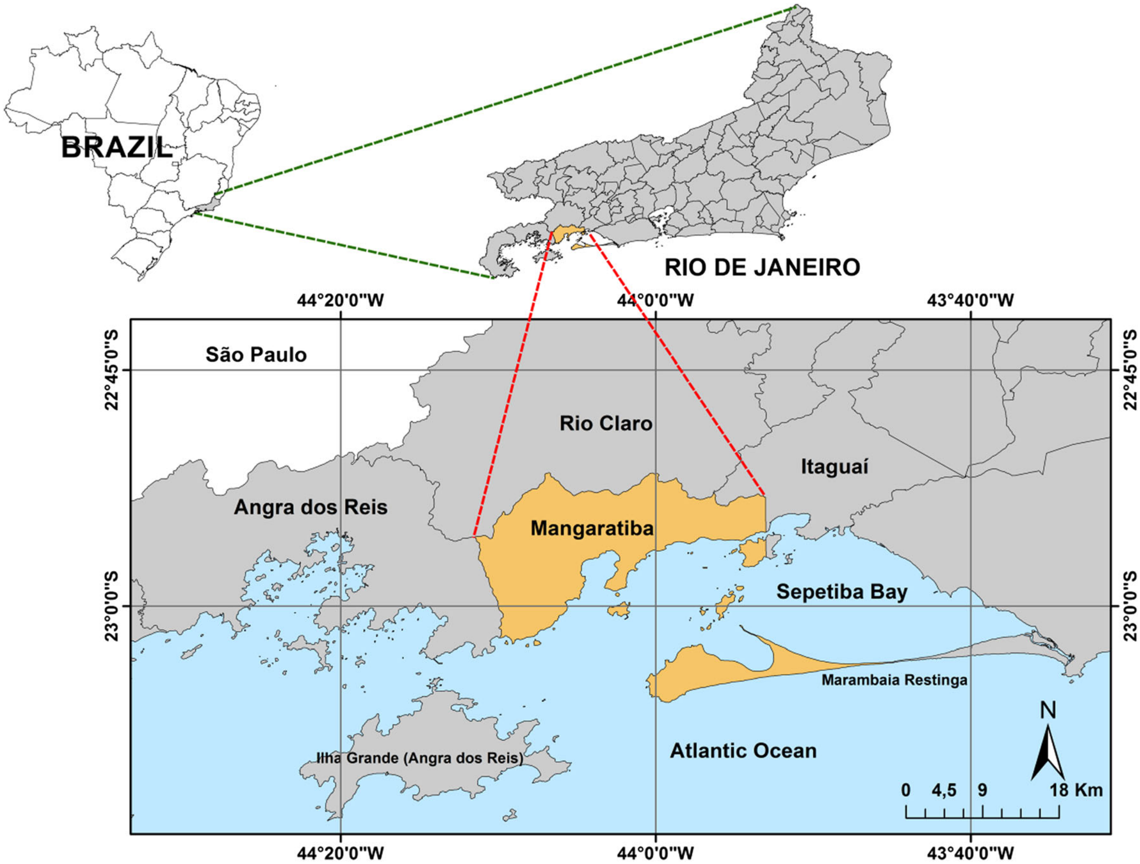

Fig. 1 Location of the municipality of Mangaratiba (in beige)

Simulation of future scenarios

The present study was based on the method of Zhang et al. (2011), as applied to the Florida Keys islands, USA. The method predicts the overlapping of the land use map to a Digital Elevation Model (DEM) and the representation of the flooded area, also allowing us to verify the potentially affected areas and to quantify the total flooded area and the flood area by class, as well as their percentages. Thus, it is possible to draw up a map showing the flooded areas for each class of land use.

The materials used were: an interferometric radar image of the SRTM (Shuttle Radar Topography Mission), resolution of 90 m, in order to generate the DEM containing the representation of the existing relief forms, through the extraction of information such as quoted points and level curves; orthophotos from photogrammetric flight, at the scale of 1: 25000 made available by IBGE, for spatial representation of the land; and digital land use map of the municipality of Mangaratiba, at the scale of 1: 25000 (version: September / 2014) made available by the State Environmental Institute (Instituto Estadual do Ambiente - INEA).

The simulation of sea-level elevation was performed with ArcGis 10.2 software, using the radar images (SRTM) next to the IBGE orthophotos. Due to the low precision of the DEM used and considering the effects of the melting of small glaciers and ice caps associated with the temperature increase, an elevation of 2.15 m was adopted, as proposed by Grinsted et al. (2009). Based on the A1FI scenario of the Fourth Assessment Report (AR4) of the IPCC (2007), this is the highest elevation value proposed in articles published in the international literature (e.g. Church and White 2006; Rahmstorf 2007; Vermeer and Rahmstorf 2009; Jevrejeva et al. 2010).

The attempt to maximize the potential effects through the elevation value adopted was based on Nicholls et al. (2014). According to the authors, extrapolations of sea level trends from the observed data are useful as a direct method for creating local sea level scenarios, especially when using DEM with low accuracy - there is no need for extremely large accurate models, since the availability of data inputs to build scenarios does not exceed the accuracy of 0.3 m at the best.

Similar methods were also used by Akumu et al. (2010), Natesan and Parthasarathy (2010), Al-Buloshi et al. (2014) and Peric and Zvonimira (2015). These authors pointed out, as a consequence, the potential for: damage to urban settlements, damage to areas of low and medium density occupation, impacts on mangrove areas, restingas and wetlands, flooding of beaches and the advancement of the coastline in relation to the current position.

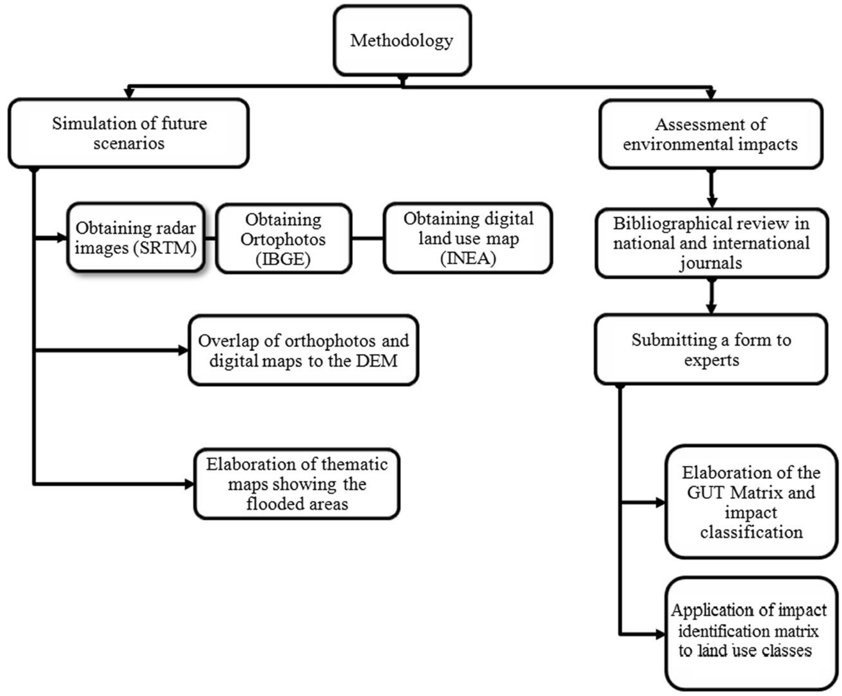

Fig. 2 Flowchart showing the applied methodology

Assessment of environmental impacts

This step of the methodology was divided into: bibliographic review; sending forms to researchers; elaboration of interaction matrix using the answers of the forms with the classification of the impacts; and the elaboration of an identification of impacts matrix with the land use, with mitigation proposals for them.

The bibliographic review was carried out using national and international journals, with the goal of investigating different environmental impacts in coastal areas caused by elevation of the sea-level. The survey was supported by a questionnaire on the Google platform (Fig. 3). This was sent to a group of 65 experts on climate change studies and their effects in coastal areas, nationwide and different areas of knowledge, including: geographers, geologists, oceanographers, environmental scientists and biologists.

In general, for each environmental impact, the researcher should assign a criticality value between 1 and 5 (1 for the least critical and 5 for the most critical scenario), taking into account severity, urgency and tendency to get worse.

The preparation of the matrix and the classification of impacts were the following steps. The interaction matrix used to evaluate the likely environmental impacts was the GUT (Gravity, Urgency and Tendency) matrix developed by Kepner and Tregoe (1981) in order to evaluate impacts and guide more complex decisions. This methodology was also applied by Medeiros and Hohlenverger (2003), Grecco et al. (2011), Vasconcelos et al. (2013) and Costa (2016), in different proposals.

With the answers obtained (assigned values) from the questionnaire, a frequency distribution of the same ones was done, adopted for each of the environmental impacts, its modal sample., The impacts were then listed with their values inserted into the variables G, U and T. Then they were multiplied, obtaining the total results and their equivalent percentages (basis for action priority).

The last step consisted of the application of impact identification matrix together with the classes of land use, based on the matrix elaborated by Leopold et al. (1971). In order to relate and evaluate the impacts extracted from the GUT matrix, its consequences and the possibility of occurrence in the study area, the actions were carried out in the following order:

First, the impacts with the highest value in each of the variables of the GUT matrix (in this case 5 being the highest level of criticality) were listed; then, through consultation with the literature, the consequences of the impacts on the coastal zone were listed. Subsequently, with the analysis of the land-use map and field work, the possible occurrence of the aforementioned impacts in each class of land use in the study area was verified. Finally, control and / or mitigation measures (based on local reality) were proposed to decision makers.

Results

Simulation of future scenarios

The simulation of SLR of the order of 2.15 m allowed us to quantify the potentially flooded area, in hectares (ha): total

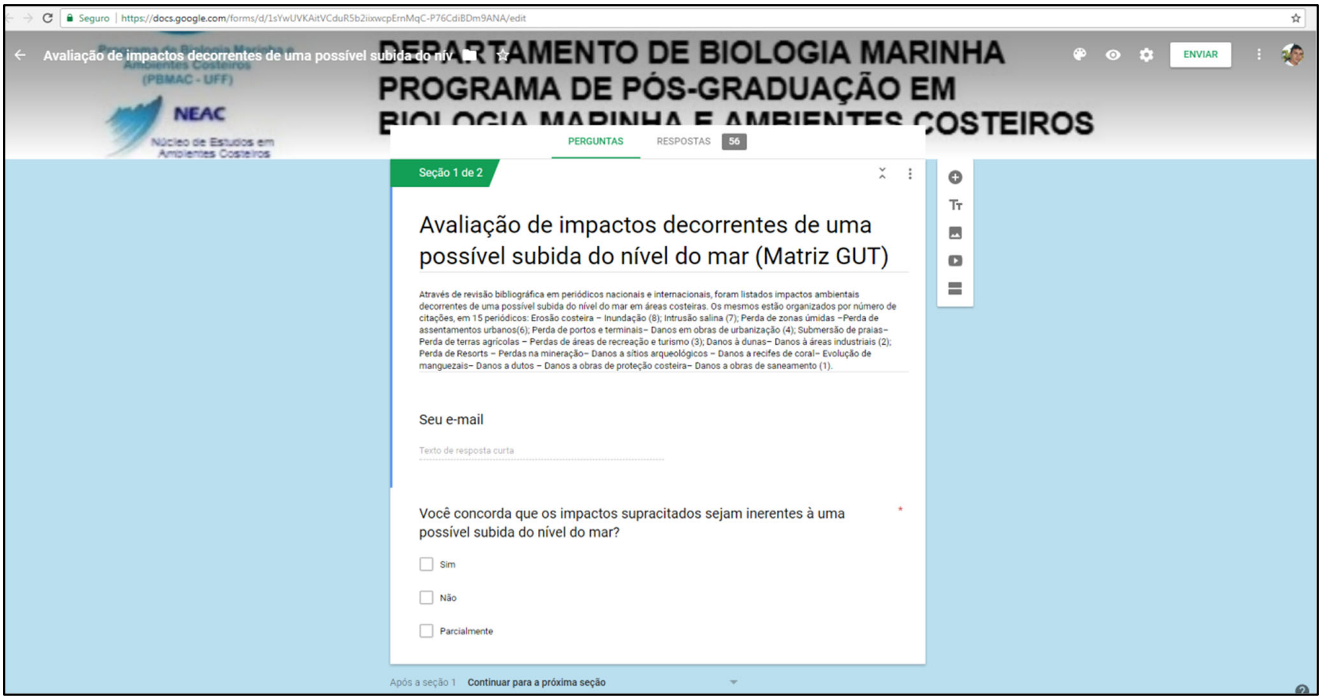

Fig. 3 Screenshot with questionnaire drawn up in form on the Google platform

flood area equal to 2573.51 ha, with a percentage equivalent to 7.40% of the total area of the municipality (34,768.61 ha). Figure 4 highlights the generated map, showing the flooded areas and the updated coastline.

Comparing the simulation with elevation of 2.15 m based on Grinsted et al. (2009) with the elevation proposed by the IPCC (0.84 m), it is possible to perceive the difference in total flood areas in the municipality (Fig. 5).

Through the overlay of the land use map to the DEM, it was possible to make a percentage survey of the flood area by class, in relation to the total flooded area (Table 1).

Assessment of environmental impacts

From the bibliographic review, 20 different environmental impacts from SLR were listed, and the most frequently

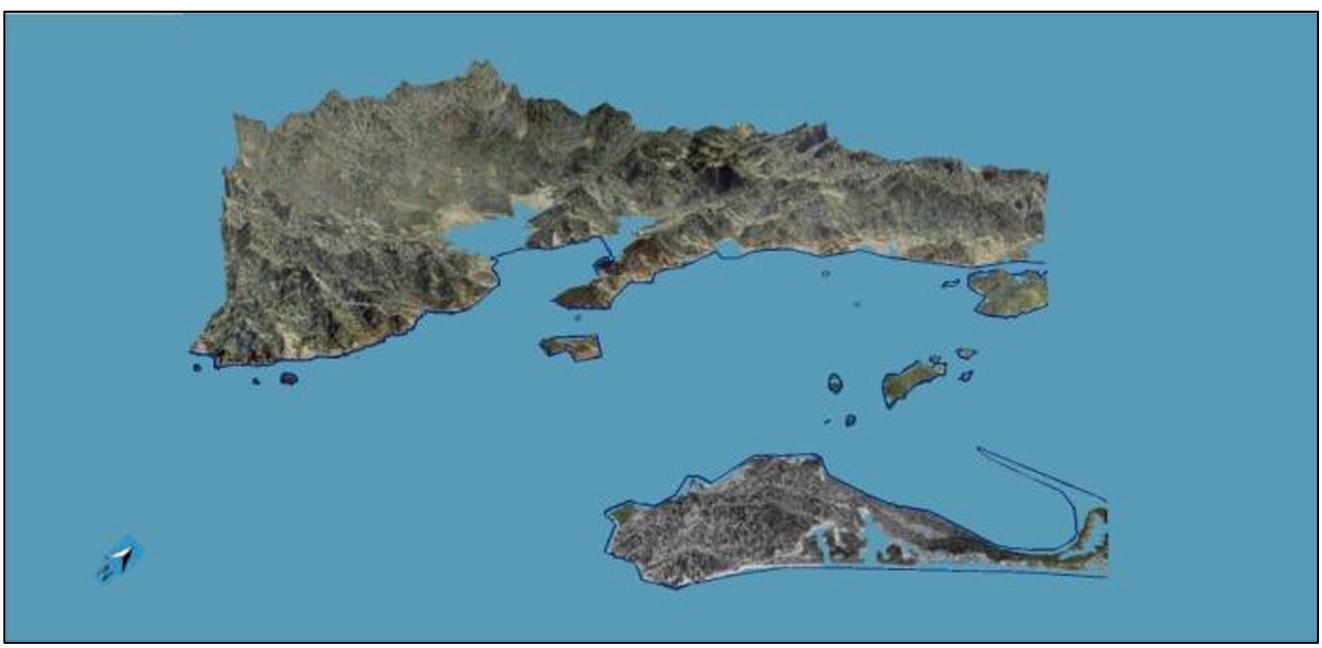

Fig. 4 Simulation of elevation of 2.15 m of sea-level visualized in the DEM elaborated for the study area (the current coastline is highlighted)

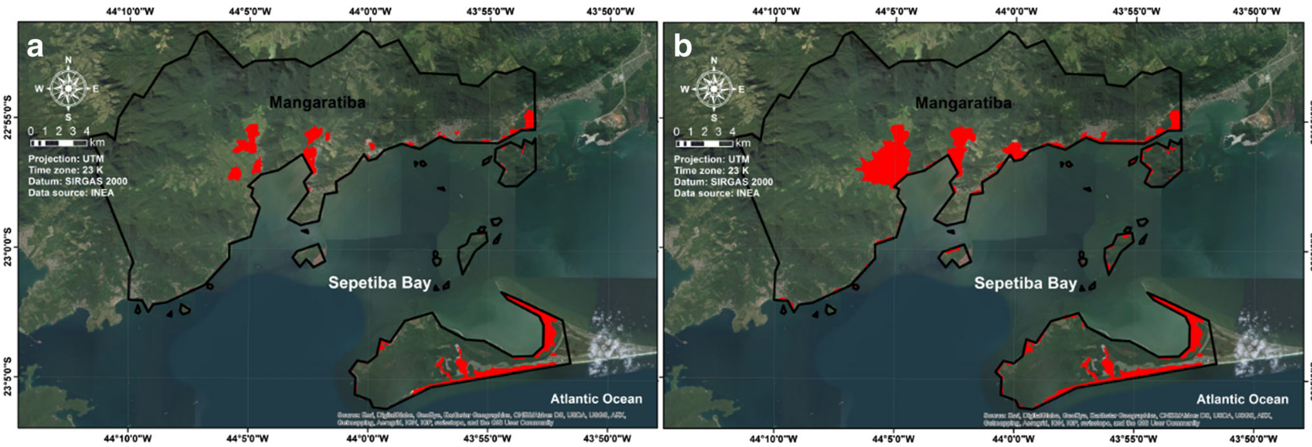

Fig. 5 Representations of the flooded area in the Municipality of Mangaratiba: **a**) IPCC – SLR of 0.82 m; **b**) Grinsted et al. (2009) – SLR of 2.15 m

mentioned were coastal erosion, saline intrusion, loss of wetlands and loss of urban settlements (Fig. 6).

With the answers given by the experts to the Google platform questionnaire, the following results were obtained: impacts of greater Gravity – coastal erosion, flooding, dune damage, damage to archaeological sites, damage to coral reefs, evolution of mangroves and damage to sanitation works; impacts of greater Urgency – coastal erosion, flooding, damage to dunes, damage to archaeological sites, damage to coral reefs and evolution of mangroves; impacts of greater Tendency – coastal erosion, flood, submersion of beaches, damages to dunes, damages to archaeological sites, damage to coral reefs and evolution of mangroves.

The Table 2 shows the filling of the GUT matrix, which allowed to gather the previously listed environmental impacts and classify them into their variables:

With the multiplication of the indexes G, U and T, it was verified that the environmental impacts with the greatest result were coastal erosion, flood, damage to the dunes, damage to archaeological sites, damage to coral reefs and evolution of mangroves. For each one of the above impacts mentioned, a product equivalent to 125 was obtained, equal to 11% each, which, together, had a total of 66% in priority action.

With the application of the impact identification matrix and classes of land use, represented in Fig. 7, using the impacts highlighted by the GUT matrix, it was possible to verify that:

Table 1 Survey (area and percentage) of the flood in the municipality of Mangaratiba by land use class - simulation of 0,82 and 2.15 m above sea level

Total area (ha)	IPCC (2013) SLR = 0,84 m		Grinsted et al. (2009) SLR = 2,15 m		Class
	Area to be flooded (ha)	Flood percentage (%)	Area to be flooded (ha)	Flood percentage (%)	
61.99	1.85	0.12	4.86	0.18	Rocky outcrop
158.67	38.73	2.54	101.57	3.94	Water
246.59	34.24	2.24	89.78	3.48	Wetlands
78.54	65.56	4.3	65.56	2.54	Beach ridges
27,837.19	300.5	19.74	338.63	13.15	Forest
134.50	86.11	5.64	86.11	3.34	Mangrove
0.10	0	0	0.10	0.004	High Density Urban Occupation
185.59	7.64	0.5	20.05	0.77	Low Density Urban Occupation
692.29	85.49	5.61	224.16	8.71	Urban Occupation of Medium Density
2,208.82	129.51	8.5	339.58	13.19	Pasture
1,147.92	308.85	20.29	809.80	31.46	Floodplain pasture
1,980.20	461.08	30.29	487.03	18.92	Restinga
36.15	2.37	0.15	6.23	0.24	Secondary forest in initial stage
34,768.61	1,521.93	100	2,573.51	100	Total

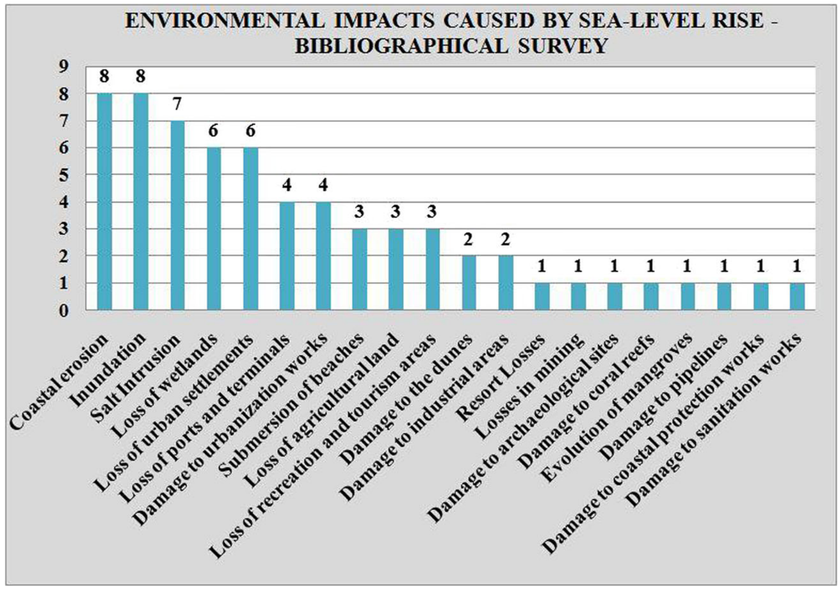

Fig. 6 Graph of the different environmental impacts found in bibliographic review by number of citations

- The consequences of these impacts (according to literature and field observation) do not apply in the case of damage to archaeological sites and coral reefs. In contrast, coastal erosion, floods, damage to dunes, and the evolution or extinction of mangroves are appropriate with to the study area;
- Regarding the possible occurrence of impacts, in each land use class, it was verified that coastal erosion, floods and damage to the dunes, all apply to the area. In the case of mangroves, only the extinction of the mangroves would be possible;
- The proposed measures of control and mitigation, according to the local reality, would only fit in the case of coastal erosion or floods.

Discussion

Although the simulation of the SLR increase has a low percentage in relation to the Mangaratiba area, it is important to highlight that the local geomorphology presents a predominance of local mountain ranges, with altimetric amplitudes between 200 and 400 m and rugged mountain ranges with altitude above 400 m (82% of the area), in the slopes facing Sepetiba Bay (Bastos and Napoleão 2010). Therefore, the effects of sea elevation will be critical in the fluvial plains, areas of sandy strands, dunes and restingas.

The simulation of SLR towards the end of this century in the Florida Keys by Zhang et al. (2011) indicated a total direct

Table 2 GUT Matrix filled. In particular, the impacts with greater gravity, urgency and tendency to worsen

GUT MATRIX					
Problem	Gravity	Urgency	Tendency	Result	Priority
Coastal Erosion	5	5	5	125	11%
Inundation	5	5	5	125	11%
Salt Intrusion	3	3	4	36	3%
Loss of wetlands	2	3	3	18	2%
Loss of urban settlements	4	4	3	48	4%
Loss of ports and terminals	3	4	3	36	3%
Damage to urbanization works	3	3	3	27	2%
Submersion of beaches	4	3	5	60	5%
Loss of agricultural land	3	3	3	27	2%
Loss of recreation and tourism areas	2	2	2	8	1%
Damage to the dunes	5	5	5	125	11%
Damage to industrial areas	3	3	4	36	3%
Resort Losses	2	2	2	8	1%
Losses in mining	2	2	2	8	1%
Damage to archaeological sites	5	5	5	125	11%
Damage to coral reefs	5	5	5	125	11%
Evolution of mangroves	5	5	5	125	11%
Damage to pipelines	3	3	3	27	2%
Damage to coastal protection works	2	4	3	24	2%
Damage to sanitation works	5	4	3	60	5%
Total				1173	100%

CLASSIFICATION OF THE IMPACT ON THE GUT MATRIX (GRAVITY - URGENCY - TENDENCY)	IMPACTS	CONSEQUENCES OF IMPACTS IN THE STUDY AREA	LAND USE CLASSES													MEASURES OF CONTROL AND MITIGATION
			Rocky Outcrop	Watercourses	Weatlands	Beach Ridges	Forest	Mangroves	High Density Urban Occupation	Low Density Urban Occupation	Medium Density Urban Occupation	Pasture	Floodplain Pasture	Restinga	Secondary forest in initial stage	
5 - Extremely serious; extremely urgent; tendency to aggravate rapidly	Coastal Erosion	Reduction in the width of the strip of sand; loss and imbalance of natural habitats; floods from storm surges; destruction of built structures; loss of tourism potential in the region; collapse of coastal ecosystems (Marengo *et al.* ,2017a,b; Muehe, 2006; Neves and Muehe, 2008; Souza and Luna, 2010; Zang *et al.* , 2011).		x	x	x	x	x	x	x	x	x	x	x	x	Carry out studies to identify indicators of coastal erosion and monitoring; identification of beaches with risk of erosion; monitoring SLR; weather and climate monitoring; risk assessment and vulnerability; conducting studies and establishing effective measures aimed at recovering critical beaches and / or mitigating coastal erosion; establishment of measures of management of the border, with indications of actions for short, medium and long term, based on studies of coastal erosion and forecasts of SLR.
	Inundation	Loss and imbalance of natural habitats; soil erosion; destruction of vegetation; destruction of built structures; impacts on urban infrastructure; loss of tourism potential in the region (Akumu *et al.* , 2010; Muehe, 2006; Neves and Muehe, 2008; Souza and Luna, 2010; Zang et al., 2011).		x	x	x	x	x	x	x	x	x	x	x	x	Reduction of flooding with the construction of dams, dams and containment works; vulnerability reduction through regulation of floodplains and the insertion of development policies; mitigation of the effects of floods through information, disaster preparedness and recovery measures.
	Damage to the dunes	Rupture of the barrier and/or migration of the dunes (Bastos and Napoleão, 2010; Santos, 2016).				x										Closed natural area controlled by the Brazilian Armed Forces - there is no possibility of control or mitigation.
	Damage to archaeological sites	Not applicable.														Not applicable in the study area.
	Damage to coral reefs	Not applicable.														Not applicable in the study area.
	Evolution of mangroves	Evolution / Extinction of mangroves (Bezerra *et al.* , 2014; Godoy and Lacerda, 2015; Lara *et al.* , 2002; Neves and Muehe, 2008; Nicholls and Cazenave, 2010).						x								Not applicable in the study area.

Fig. 7 Matrix of identification of impacts and classes of land use filled

flood equivalent to 91% of the area of the island. However, even though the percentage of flood is much lower than the island of the Florida Keys, the Mangaratiba plain has a similar degree of criticality in the case of a marine transgression.

The work of Bosello et al. (2012) points out that by the end of the century (with an RSL increase of 0.88 m) the loss of land in Malta and Greece would be a total of 12 and 3.5%, respectively. Even using an elevation value below that proposed in the simulation for Mangaratiba, it is possible to notice some similarity, since the flood has a great impact on the plains of the mentioned countries. All the mentioned areas have added importance due to the high population concentration.

With the simulation of SLR, it was possible to superimpose the flooded area to the geomorphological map of the municipality, noting that the flood will only cover low areas: fluvial (and fluvial-marine) plains, beach ridges areas, dunes and restingas (Fig. 8).

The survey of the flood area, along with the identification of the land use classes of Mangaratiba as evidenced by Fig. 9, showed a higher impact on pastures, restingas, forests and medium density urban occupation areas, all present in areas with flatter and lower relief. This in agreement with the results obtained by Akumu et al. (2010), Natesan and Parthasarathy (2010), Zhang et al. (2011) Al-Buloshi et al. (2014) and Peric and Zvonimira (2015). These studies indicate the effects of damage to urban settlements, areas of low and medium density occupation, impacts on mangrove areas, restingas and wetlands, flooding of beaches and the advancement of the coastline in relation to the current position.

Regarding the economic impact, according to data obtained from the municipal planning office, the value of the square meter of land is equivalent to 3571 reais (US$ 876.11). For a future scenario with the loss of 2573.51 ha of area, it is estimated to represent an economic loss of the order of 91.90 billion reais (US$ 22.54 billion).

The results obtained through the proposed methodology indicate similarities between the study area and several areas mentioned in the literature. With the use of the GUT matrix followed by the application of the impacts identification matrix and land use classes, it was concluded that among the six that presented the highest degree of action priority, coastal erosion and floods demand greater attention, and their consequences have already been verified in the study area (e.g. Oliveira and Moura 2008).

According to Pickering et al. (2017), it is of great importance to analyze the floods caused by tidal changes due to SLR. Erosion and flooding are events that may cause an imbalance in the coastal dynamics of Sepetiba Bay (Muehe 2006). In fact, the storm surge at Praia do Saco in November 2016 (Passos et al. 2017) caused damage to the protection of the boardwalk, sand advancement on the boardwalk and in Rio de Janeiro Avenue, as shown in Fig. 10.

Praia do Saco is one of the most sought after locations by tourists in all the municipality. Tourism is a vocation in Mangaratiba, and the municipality is one of the most sought

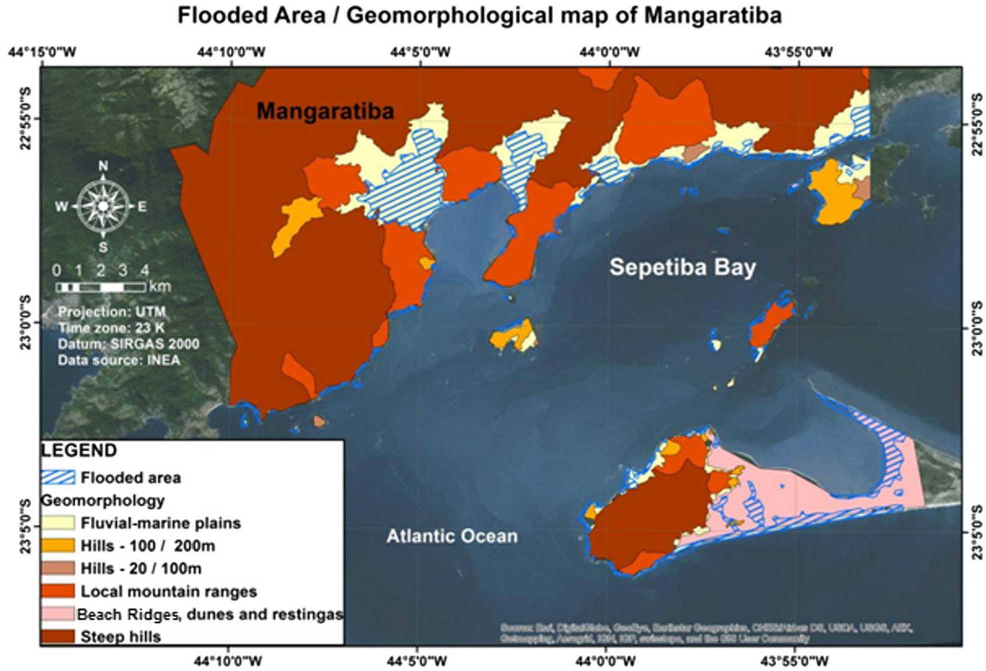

Fig. 8 Simulation of SLR, in the order of 2.15 m, confronting the geomorphological map of the municipality

after in the Rio de Janeiro state, according to the Ministry of Tourism (FIPE 2007). Its activities represent important sources of employment and income for the population of the municipality, with emphasis on the local economy.

According to information obtained from the Municipal Government of Mangaratiba, costs related to cleaning repairs to damage caused by these events are high, and the values can vary between 100,000 reais (US$ 24,358) and 500,000 reais (US$121,790), according to their magnitude. In addition, the occurrence of events such as storm surges and can cause other significant impacts on the local economy: characterized by the devaluation of real estate (which can reach a fall of 70% of value), decrease in tourist demand and costs with cleaning and repairs in ventures such as restaurants, for example.

Regarding the control and mitigation measures for coastal erosion and floods, the proposals included in the matrix are relevant to the reality of the study area. For this purpose, it is necessary to align the public power structures with the research institutions, aiming at adopting public policies and techniques that promote the implementation of actions.

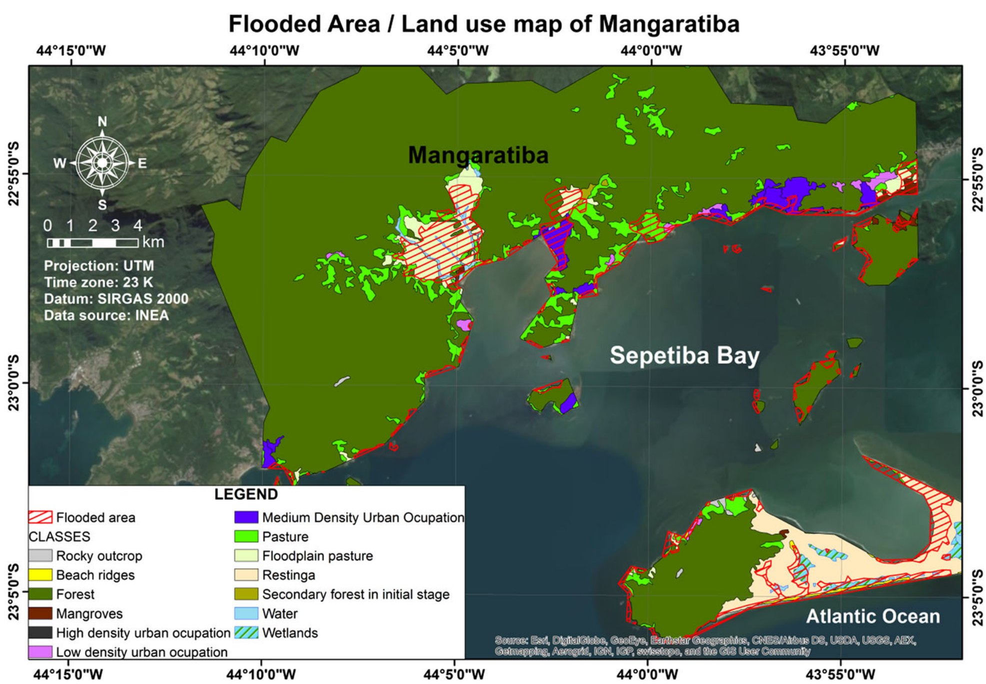

Fig. 9 Representation of the flooded area in the municipality of Mangaratiba, with overlay of the land use class map - simulation of 2.15 m above sea-level

Fig. 10 Effects of the storm surge at Saco beach - Mangaratiba: **a**) Breakage of part of the boardwalk protection; **b**, **c** and **d**) Sand advance on the boardwalk and Rio de Janeiro Avenue

The damage to the dunes and the evolution of the mangroves were highlighted as impacts by the GUT matrix. However, the impact identification matrix and land use classes showed that they do not apply to all classes of land use, but they demand concern.

The SLR in this area may have consequences such as breaking the barrier and/or migration of the dunes, and in case of intensification of the process. In addition, the migration of the barrier to the interior of Sepetiba Bay (Santos 2016) may also occur. However, any type of intervention and mitigation of impacts is the responsibility of the Federal Government, as it is a Federal area controlled by the Brazilian Armed Forces.

The mangroves of the municipality of Mangaratiba, located in the District of Itacuruçá (Ribeiro 2012; Silva et al. 2013), are vulnerable to possible flooding, which could lead to the extinction of this ecosystem in the area. In case of migration, there is no viability for this, since they depend on low relief with an extensive flat area (Lara et al. 2002; Neves and Muehe 2008; Nicholls and Cazenave 2010; Godoy and Lacerda 2015), which contrasts with the local geomorphology, where the highest areas are very close to the low-lying areas.

The damage to the archaeological sites was also pointed out in the GUT matrix, but when faced with the existing land use classes, they did not present a significant problem. The Guaíba site (Schmitz 1987) is in an altimetric quota that would not be affected by the SLR.

In relation to the reef environments, they would not be susceptible to damages caused by the SLR (Neves and Muehe 2008). In the study area, the concern is more strongly related to the warming of the waters caused by climate change, which may cause coral weakening and/or mortality (Rutz and Souza 2015) and the invasion of exotic species in Ilha Grande Bay (Paula and Creed 2005).

Conclusions

The simulation of SLR based on the work of Grinsted et al. (2009), allowed us to show that the percentage of flood in Mangaratiba, even where expressing a low percentage, will have a devastating effect. According to the land use map, there is intense urban concentration in the plains areas, besides the presence of pastures, restingas, dunes, forests and mangroves, in the areas of fluvial-marine plains and beach ridges.

The use of the GUT matrix made it possible to evaluate the environmental impacts, and some of the impacts caused by the increase in NM, are considered to be of greater severity, urgency and trend, and these are compatible with the study area, such as coastal erosion and coastal flooding, phenomena that are already frequent in the study area.

Finally, the continuation of this work and the adoption of preventive measures by the local authorities are of great importance, both in the socio-environmental and academic aspects. Through this work it is now possible, besides raising the environmental impacts resulting from a SLR, to verify that some aspects are appropriate to the study area: coastal erosion and flooding, for example, are in fact phenomena arising in it.

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