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Sea level rise and its likely impacts: a case study in the coast of Mangaratiba-RJ

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Abstract. The state of Rio de Janeiro follows a 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 on 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 likely 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 flooding, coastal erosion, damage to areas of urban occupation and to the dunes, which could directly affect the infrastructure, housing and local tourism.

Key words: Coastal geomorphology, Global climate change, Future scenarios, Environmental impact

Resumo: Elevação do nível do mar e seus possíveis impactos: um estudo de caso na costa de Mangaratiba-RJ. O estado do Rio de Janeiro segue uma tendência mundial de crescimento populacional na zona costeira, com grandes condomínios e incipiente comércio local em seu entorno. Suas praias estão sujeitas a impactos ambientais causados pela elevação do nível relativo do mar, que podem ser intensificados, sobretudo, por pressões oriundas de atividades antrópicas. Foi elaborada uma simulação de subida do nível relativo do mar no município de Mangaratiba, enfatizando suas áreas de inundação a partir da transgressão marinha. Com a sobreposição da área alagada ao mapa de uso do solo, foi possível quantificar a inundação em cada uma das classes. Posteriormente, através de levantamento bibliográfico e aplicação de matrizes de interação e listagens, foi possível avaliar prováveis impactos ambientais provenientes da inundação supracitada. O resultado mostrou que uma subida do nível relativo do mar na área de estudo terá consequências como processos de erosão costeira, inundações, danos às áreas de ocupação urbana e danos às dunas, que poderão interferir diretamente na infraestrutura, no parque habitacional e no turismo local.

Palavras-chave: Geomorfologia costeira, Mudanças climáticas globais, Cenários futuros, Impacto ambiental.

Introduction

The elevation process of the worldwide relative sea-level (RSL) is caused mainly by the addition of fresh water in the ocean basin (result of the partial melting of the ice masses stored on the continents) and the thermal expansion of the oceans, consequences of the global temperature increase (*e.g.* IPCC 2007, 2013, Cazenave & Llovel 2010).

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 20th century. Also according to this report, it is estimated an increase rate between 0.52 m and 0.98 m by the year 2100.

The National Oceanic and Atmospheric Administration (NOAA), which provides sea level variation data on the coast of Rio de Janeiro, based on information provided by the Brazilian Navy, projected a RSL by 2.18 mm yr^{-1}, equivalent to 21.8 cm in 100 years - a variation indicating a rising sea level trend in the near future (NOAA 2017). However, the Pereira Passos Institute (IPP) estimates an elevation of 1.5 m by 2100 in the Rio de Janeiro area (IPP 2008), indicating a similarity with authors in the world literature (*e.g.* Jevrejeva *et al.* (2010) – 0.6/1.60 m, Vermeer & Rahmstorf (2009) – 0.75/1.9 m).

Climate change and an accelerated elevation pace of SLR also show their serious effects on the coastal areas of Brazil, including erosion in the oceanic and estuarine coastline (Marengo *et al.* 2017a, b). This subject has been approached by several works in all Brazilian coastal area (*e.g.* Barbosa *et al.* 1999, Albino *et al.* 2001, Klein & Menezes 2001, Souza & Suguio 2003, Dillenburg *et al.* 2004, Silva *et al.* 2007, Silva *et al.* 2008, Szlafsztein & Sterr 2007, Morais *et al.* 2008, Souza & Luna 2010, Amaro *et al.* 2015) – In similarity to the work elaborated by Muehe (2006), Figure 1 highlights some works done in the Brazilian coast.

Related to the state of Rio de Janeiro, the impacts are pointed out in the works of: Oliveira *et al.* (2008), 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.

According to the Brazilian Institute of Geography and Statistics (IBGE), 26.6% of the Brazilian population lives in coastal municipalities, equivalent to 50.7 million inhabitants (IBGE 2011). Mangaratiba is one of the municipalities that compose the Macro-region of Costa Verde, on the southern coast of the Rio de Janeiro state. According to the Brazilian Institute of Geography and Statistics (IBGE), 26.6% of theBrazilian population lives in coastal municipalities, equivalent to 50.7 million inhabitants (IBGE 2011). Mangaratiba is one of the municipalities that compose the Macro-region of Costa Verde, on the southern coast of the Rio de Janeiro state (Fig. 2). It occupies an area of 347.68 km² 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 bathed to the south by the Sepetiba Bay and the Atlantic Ocean. The municipality has more than 34 sandy beaches – some highlighted in figure 3.

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 (Borges 1998). 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. 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 (Fragoso 1995).

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 an object of dispute between the urban-industrial-port expansion and the tourism and fishing activities, historically associated to the natural heritage. On the other hand, on the ocean's edge of the municipality, Restinga da Marambaia is a very preserved area.

There is a trend of population growth: between 2000 and 2010, the population of Mangaratiba grew at an average rate of 3.89%, therefore more than double of the Brazilian rate of 1.17% in the same period (the urbanization of the

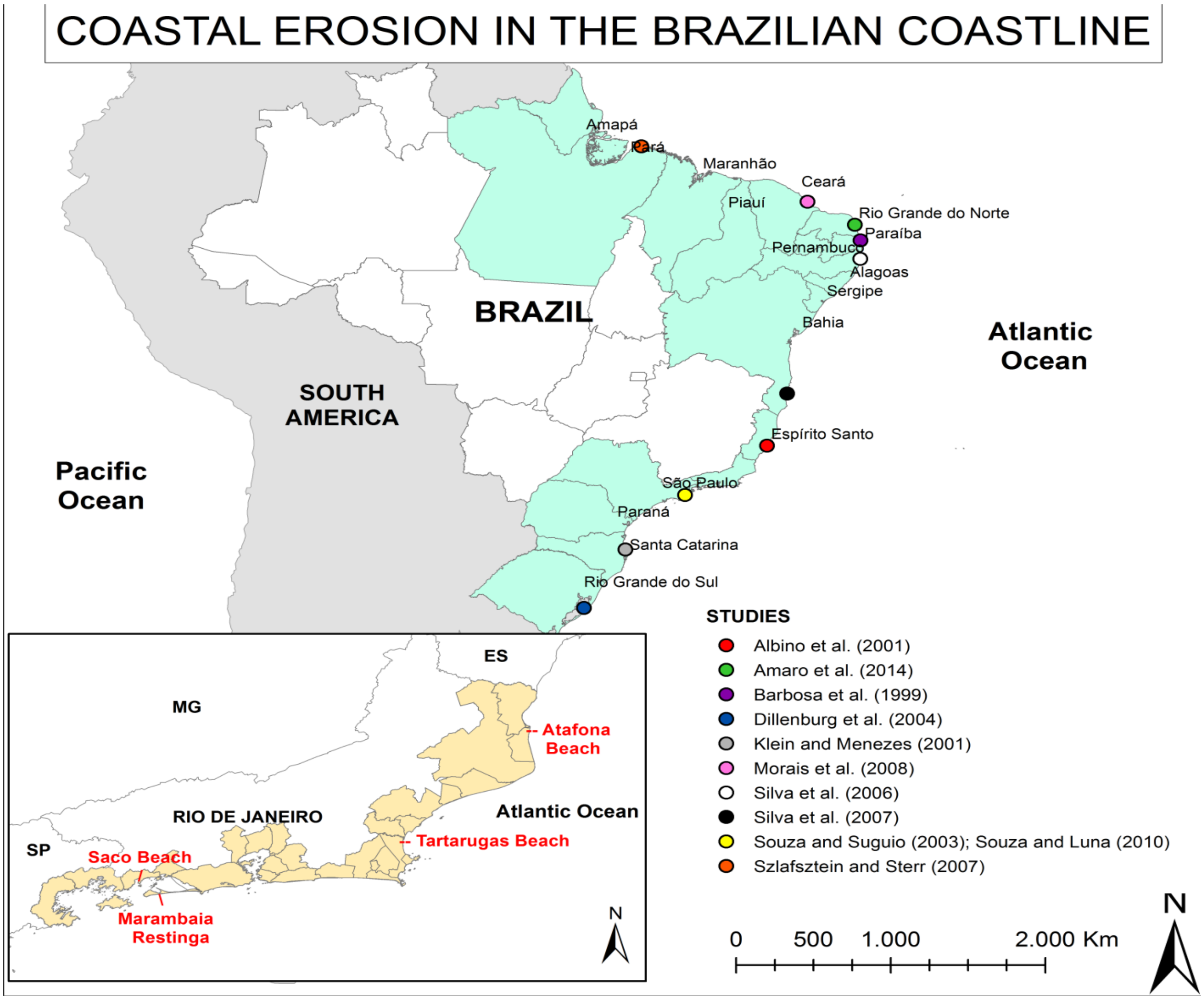

Figure 1. Map showing coastal erosion points in the Brazilian coast, according to the literature. In particular, suffering erosion in the state of Rio de Janeiro is shown.

municipality went from 79.76% to 88.11%). Meanwhile, in 2010, 36,456 inhabitants lived in the municipality, according to the latest population census of 2010 (IBGE 2011).

In this context, the present work tested a methodological routine based on the simulation of future scenarios of the elevation quotes of RSL, in the coast of Rio de Janeiro state, and particularly in the municipality of Mangaratiba. The objective of this research was to achieve 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.

Materials and 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 few decades around the world (*e.g.* Snoussi *et al.* 2007, Akumu *et al.* 2010, Nathesan & Parthasarathy 2010; Niang *et al.* 2010, Al-Buloshi *et al.* 2014).

Simulation of future scenarios: The present study was based on the method of Zhang *et al.* (2011), applied to the Florida Keys islands, USA. The materials used were: an interferometric radar image of the SRTM (Shuttle Radar Topography Mission), resolution of 90 meters, in order to generate the Digital Elevation Model (DEM) containing the representation of the existing relief forms, through the extraction of information such as quoted points and level curves (generated in the ArcGis 10.2 software, from the extension: Spatial Analyst Tool / Surface / Contour); orthophotos from photogrammetric flight, in the scale 1:25,000 made available by IBGE, for spatial representation of the land; and digital land use map of the municipality of Mangaratiba, in the scale 1:25,000 (version:

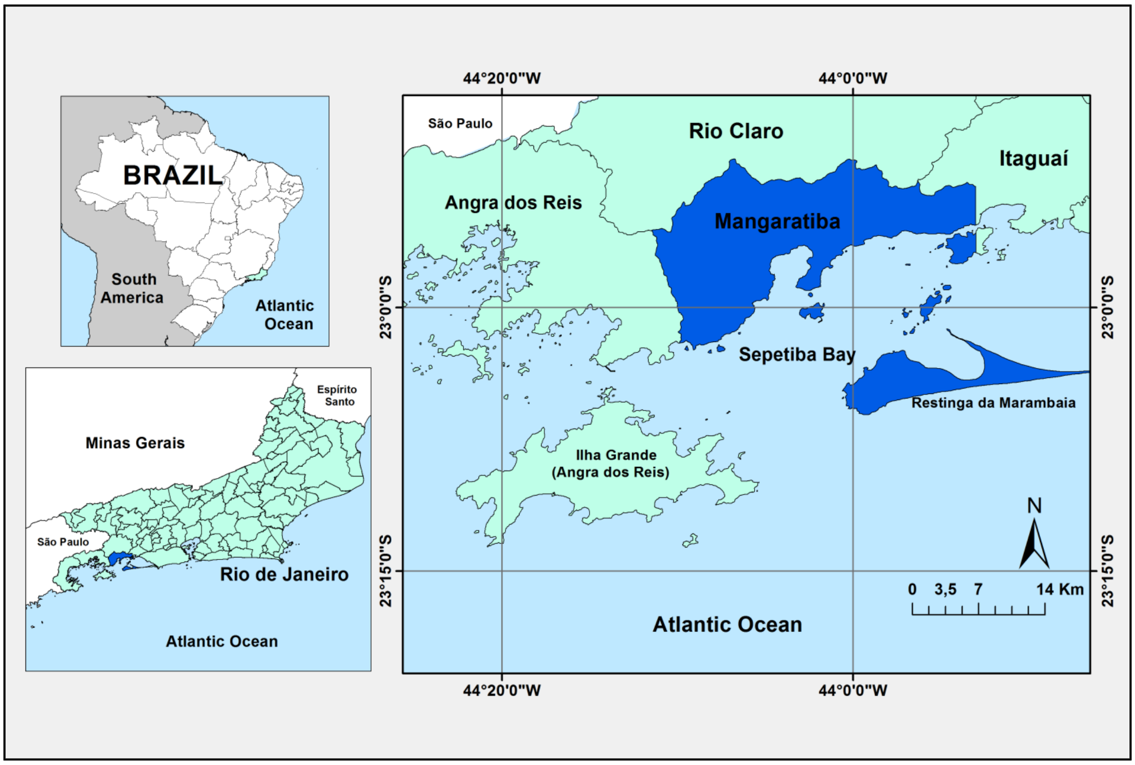

Figure 2. Location of the municipality of Mangaratiba.

Figure 3. Sandy beaches of the municipality of Mangaratiba: **A)** Itacuruçá; **B)** Muriqui; **C)** Sahy; **D)** Mangaratiba Central Beach; **E)** Saco; and **F)** Conceição de Jacareí.

September/2014) made available by the State Environmental Institute (INEA).

The simulation of sea-level elevation was performed in the ArcGis 10.2 software, using the radar images (SRTM) next to the IBGE orthophotos. For this, the elevation rate of 2.15 m was adopted, 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 rate among the values proposed in articles published in the international literature (*e.g.* Church & White 2006, Rahmstorf 2007, Vermeer & Rahmstorf 2009, Jevrejeva *et al.* 2010).

Similar methods were also used by Akumu *et al.* (2010), Natesan & Parthasarathy (2010), Al-Buloshi *et al.* (2014) and Peric & Zvonimira (2015). These authors pointed out, as a consequence, damages to urban settlements, damages 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.

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

The bibliographic review was carried out in national and international journals using keywords such as “sea level rise”, “environmental impacts” and “coastal zone”, with the goal of raising different environmental impacts in coastal areas caused by elevation of the sea-level. The survey was supported by a questionnaire on the Google platform: 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.

The first questioning that was asked if the researcher agreed with the impacts cited in the bibliographical survey are inherent to a sea level rise; In the second questioning was asked which grade (between 1 and 5) the researcher would give for each environmental impact previously raised, taking into account its gravity, urgency and tendency.

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 – responses were tabulated through their frequency distribution. Then, the statistical mode was adopted for each of the environmental impacts.

The preparation of the matrix and the classification of impacts had the following steps. The interaction matrix used to evaluate the likely environmental impacts was the GUT (Gravity, Urgency and Tendency) matrix developed by Kepner & Tregoe (1981) in order to evaluate impacts and guide more complex decisions. This methodology was also applied by Grecco *et al.* (2011) and Vasconcelos *et al.* (2013), in different proposals, with issues involving current processes.

With the obtained answers (assigned values) from the questionnaire, a frequency distribution of the same ones was done, adopted for each of the environmental impacts, its modal sample. Then, the impacts were 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 in 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, higher level of criticality) were listed; then, through consultation with the literature, the consequences of the impacts on the coastal zone were listed; then, with the analysis of the land use map and field work, it was verified the possible occurrence of the aforementioned impacts in each class of land use in the study area. Finally, control and / or mitigation measures (based on local reality) were proposed to decision makers.

Results

Simulation of future scenarios: The simulation of SLR in the order of 2.15 m allowed quantifying the flooded area, in hectares (ha): total flood area equal to 2,573.51 ha, with a percentage equivalent to 7.40% of the total area of the municipality (34,768.61 ha).

The survey of the flood area along with the identification of the land use classes of Mangaratiba, evidenced by Figure 4, showed a higher impact on pastures, restingas, forests and medium density urban occupation areas.

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 I).

Environmental impact assessment: From the bibliographic review, 20 different environmental impacts from SLR were listed, and the most frequently mentioned were coastal erosion, saline intrusion, loss of wetlands and loss of urban settlements.

With the answers given by the 65 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

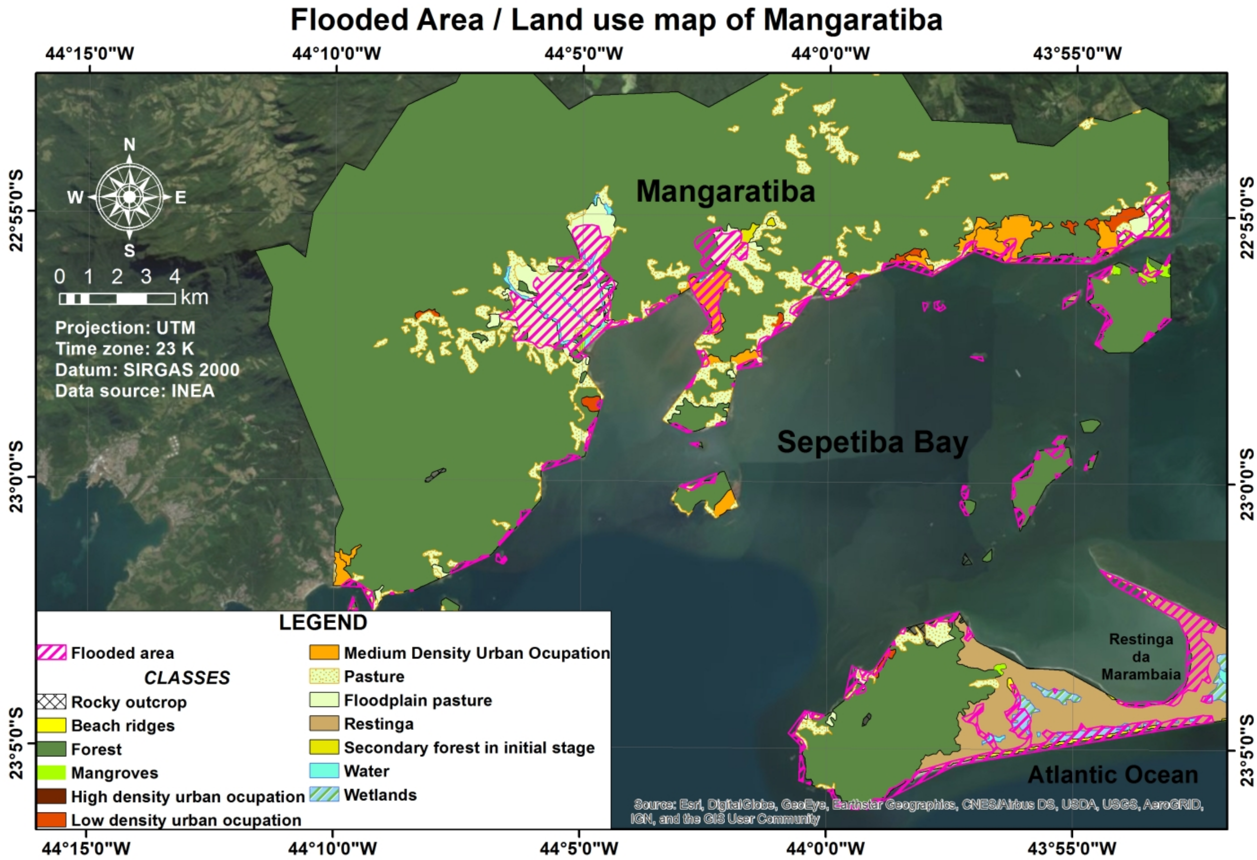

Figure 4. Representation of the flooded area in the municipality of Mangaratiba, with overlay of the land use class map - simulation of 2.15 m above sea level.

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

Class	Total area (ha)	Area to be flooded (ha)	Flood percentage (%)
Rocky Outcrop	61.99	4.86	0.18
Watercourses	158.67	101.57	3.94
Weatlands	246.59	89.78	3.48
Beach Ridges	78.54	65.56	2.54
Forest	27,837.19	338.63	13.15
Mangroves	134.50	86.11	3.34
High Density Urban Occupation	0.10	0.10	0.004
Low Density Urban Occupation	185.59	20.05	0.77
Medium Density Urban Occupation	692.29	224.16	8.71
Pasture	2,208.82	339.58	13.19
Floodplain Pasture	1,147.92	809.80	31.46
Restinga	1,980.20	487.03	18.92
Secondary forest in initial stage	36.15	6.23	0.24
Total	**34,768.61**	**2,573.51**	**100**

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 II 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 considered 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 Figure 5, using the impacts highlighted by the GUT matrix, it was possible to verify that:

• 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 compatible with 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, applies 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 RSL 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 slope facing the Sepetiba Bay (Bastos & Napoleão 2010). Therefore, the effects of sea elevation will be critical in the fluvial plains, areas of sandy strands, dunes and restingas.

For the lowland areas of the municipality, it is important to note that: according to data from the latest IBGE census (2011) there are a total of 31,517 private and collective households, of which 11,817 are permanently occupied and 19,700 are unoccupied or second homes. The population living in occupied dwellings is equivalent to 36,456 people – the effects of an SLR would result in a large social loss in the area.

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, the six that presented the highest degree of action priority, coastal erosion and floods demand greater attention, and their consequences are already verified in the study area (*e.g.* Oliveira *et al.* 2008).

According to Muehe (2006), erosion and flooding are process/events that may cause an imbalance across the coastal dynamics of Sepetiba Bay. In fact, the storm surge at Praia do Saco in November 2016 (Passos *et al.* 2017) caused damages in the protection of the boardwalk, sand advancement on the boardwalk and in Rio de Janeiro Avenue.

About 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 with the research institutions, aiming at adopting public policies and techniques that promote the implementation of actions.

The damages to the dunes and the evolution of the mangroves were highlighted 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.

In the landscape of Mangaratiba, stands out the Restinga de Marambaia, a narrow sandstone (maximum width of 5,000 m and minimum of 20 m) anchored in the basis (Guaratiba Hill), which extends eastwards towards the Telégrafo Stone

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

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%**

(Borges 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 & Napoleão 2010).

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 the Sepetiba Bay (Santos 2016) may also occur. However, any type of intervention and mitigation of impacts is 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 concerned about possible flooding, which can lead to extinction in the area. In case of migration, there is no viability, since they depend on low relief with an extensive flat area (Lara *et al.* 2002, Neves & Muehe 2008, Nicholls & Cazenave 2010, Bezerra *et al.* 2014, Godoy & Lacerda 2015), different from the local geomorphology, where the highest areas are very close to the low areas.

Figure 5. Matrix of identification of impacts and classes of land use filled.

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 (Muehe 2006, Neves & Muehe 2008, Souza & Luna 2010, Zhang *et al.* 2011, Marengo *et al.* 2017a,b).	⊘	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	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 (Muehe 2006, Neves & Muehe 2008, Akumu *et al.* 2010, Souza & Luna 2010, Zhang *et al.* 2011).	⊘	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	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 & Napoleão 2010, Santos 2016).	⊘	⊘	⊘	✓	⊘	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	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 (Lara *et al.* 2002, Neves & Muehe 2008, Nicholls & Cazenave 2010, Bezerra *et al.* 2014, Godoy & Lacerda 2015).	⊘	⊘	⊘	⊘	⊘	✓	⊘	⊘	⊘	⊘	⊘	⊘	⊘	Not applicable in the study area.

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 relation. The Guaíba site (Schmitz 1987) is in 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 & Muehe 2008). In the study area, the concern is related to the warming of the waters caused by climate change, which may cause coral weakening and/or mortality (Rutz & Souza 2015) and the invasion of exotic species in Ilha Grande Bay (Paula & Creed 2005).

Conclusion

The method of simulation of SLR allowed to show that the percentage of flood in Mangaratiba, even with a low percentage (due to its predominant geomorphology of hills), 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 bibliographical review with the questionnaire of the Google platform, not only allowed to raise the environmental impacts due to a

SLR, but also to verify that some are compatible with the study area. Thus, the contribution of the specialists involved was essential.

The use of the GUT matrix next the Matrix of identification of impacts and classes of land use made it possible to evaluate the environmental impacts, and some of the impacts caused by the SLR, considered to be of greater gravity, urgency and tendency, are compatible with the study area, such as coastal erosion and coastal flooding, phenomena already frequent in study area.

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

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