Environmental and Anthropogenic Indicators for Coastal Risk Assessment at Massaguaçú Beach (SP) Brazil

Article *in* Journal of Coastal Research · January 2011

Paulo H. Sousa
Universidade Federal do Ceará

Eduardo Siegle
University of São Paulo

Journal of Coastal Research	SI 64	319 - 323	ICS2011 (Proceedings)	Poland	ISSN 0749-0208

Environmental and Anthropogenic Indicators for Coastal Risk Assessment at Massaguaçú Beach (SP) Brazil

P. H. G. O. Sousa†, E. Siegle† and M. G. Tessler†
†Instituto
Oceanográfico
Universidade de São
Paulo, São Paulo
05508120, Brazil
sousaph@usp.br;
esiegle@usp.br;
mgtessle@usp.br

ABSTRACT

Sousa, P. H. G. O.; Siegle, E. and Tessler, M. G., 2011. Environmental and Anthropogenic Indicators for Coastal Risk Assessment at Massaguaçú Beach (SP) Brazil, SI 64 (Proceedings of the 11th International Coastal Symposium), 319 – 323. Szczecin, Poland, ISSN 0749-0208

As a widespread trend, coastal erosion is occurring on many countries around the world. In general, such process is translated in environmental and socioeconomic damages in many coastal cities. The aim of this work is to use environmental and anthropogenic indicators to manage natural resources and subsidize regional planning. The study site is Massaguaçú Beach in Caraguatatuba, Northern Coast of São Paulo State, Brazil. The beach has been divided into three sectors and classified according to its risk in low, moderate and high. The indicators are beach profile, shoreline position, dune field, offshore settings, presence of rivers and/or inlets, terrain elevation, vegetation, coastal engineering structures, occupation rate and soil permeability. General information on these variables were extracted through remote sensing and geoprocessing techniques. The three beach sectors present different alongshore length, but a constant cross-shore distance of 500 m landwards from the water line. Sector 1, the southern part of the beach, is marked by the presence of the Massaguaçú River; sector 2, central part, concentrates the urban settlement; and sector 3, in the north, comprehends the Bracuí River and the landforms restricts the occupation in this area. Sectors 1 and 3 were classified as being of moderate risk, while sector 2 as being of high risk. Although the occupation rate is not too high, it has limited the beach profile and sediment budget. Any interventions in Massaguaçú should consider the sediment budget behavior and erosive trends.

ADDITIONAL INDEX WORDS: *Coastal Erosion, Occupation, Urban Planning.*

INTRODUCTION

The attractiveness of the coastal zone has contributed to its occupation process over time. The development of commercial relationships, goods transport, implementation of harbors and setting and expansion of urban settlements, worked as birthplace of many coastal cities. Additionally, with the growing tourism industry in the second half of the last century, the occupation process was strongly intensified. Cases where urban expansion occurred in harmony with preservation and maintenance of coastal resources are rare. In general, inadequate management of coasts resulted in the degradation of vegetation and dunes, changes on beach morphology and sediment balance.

Recent estimates indicate that approximately 1.2 billion people live near coastal zones (Small & Nicholls, 2003), making a considerable percentage subject to coastal hazards in short term, such as storm surges (Fiore et al. 2009), earthquakes (Correa & Gonzalez, 2000) and tsunamis (Srinivasalu et al, 2007), and in long term when considering the sea level rise, whose risks are related both to human and economic losses.

Coastal erosion has become a global concern over the last decades. According to Bird (1985), between 1976 and 1984, 70 per cent of beach-fringed coastlines were retreating, with only less than 10 per cent advancing. Causes of coastal erosion are often integrated factors composed of natural (Frederici & Rodolfi, 2001; Cai et al., 2009) and/or anthropogenic agents (Cooper & Mckenna, 2008, Sousa et al., 2008; Melloul & Collin, 2009). In order to reduce erosive impacts on coasts, substantial amounts of funds are employed in coastal engineering structures. These interventions are helpful solutions largely used; nonetheless, they compromise beach morphodynamics and hydrodynamics, coastal sediment transport, and its scenic beauty and functionality. Furthermore, the maintenance of these structures is carried out at elevated costs and transference of erosion to adjacent beaches or even their failure may occur (Dornbusch el al., 2007). Despite the need of some structures, they may cause damages to the local ecosystems even at regional scales (Airoldi et. al., 2005).

Although several studies consider only natural aspects for morphodynamic changes (Boruff, 2005), human activities have an important role. In many cases, anthropic agents are the catalysts for erosive processes (e.g. Xue et al., 2009; Stanica et al, 2007).

Risk assessment techniques have been developed and improved during the last decades considering several variables like stability and characteristics of the beach (Dal Cin & Simeoni, 1994), geoindicators (Bush et al., 1999), susceptibility to sea-level rise (Thieler & Hammar-Klose, 1999), and physical and human indicators (Meur-Férec et al. 2008).

The aim of this paper is to assess the coastal risks for Massaguaçú using environmental and anthropogenic indicators, thereby providing information for the better management of natural resources and to subsidize regional planning.

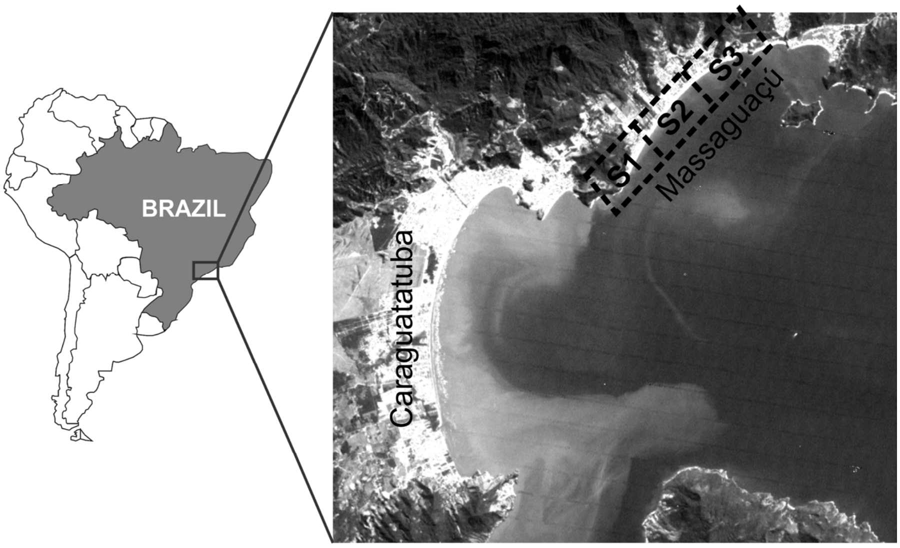

Figure 1. Study area with the indication of the coastal sectors,

Study Site

Massaguaçú is a 7.5 km long embayed beach with NE-SW orientation located in Caraguatatuba, embedded at the basis of the Serra do Mar range at the northern coast of São Paulo State (Figure 1). Two small rivers cross the short Massaguaçú coastal plain, with the Capricórnio river reaching the ocean at its southern end and the Bracuí river in the northern portion of the beach. The wave is partially sheltered from incoming waves by the São Sebastião island (south) and by the smaller Cocanha island in the north. Dominant waves in the region are from the southern and eastern quadrants (Pianca et al, 2010).

METHODS

The methods consist of assessing existing field data sets and the application of remote sensing techniques to feed the database (Table 1) on spreadsheets and SIG environment.

In this work, the selected indicators follow those proposed by Bush et al. (1999), however, variables and indicators were adapted

Table 1: Environmental and urban indicators used to evaluate the coastal risk to erosive processes at Massaguaçú beach. (Adapted from Bush et al., 1999).

Risk Indicators	Low Risk	Moderate Risk	High Risk
Beach profile	Good sand supply and extensive beach profile	Potential interruption of sediment supply and moderate to narrow beach profile	Narrow beach with sediment supply interrupted or compromised
Shoreline position	Progradation	Stable	Retrogradation
Dune field configuration	Presence of extensive and high dune field	Presence of sparse and short dunes	Absence of dunes
Offshore settings	Presence of natural barriers (islands, reefs or beach rocks)	Limited fetch (presence of sandy bars offshore)	Wide fetch with no natural obstacles minimizing wave energy
Presence of rivers and/or inlets	> 100m	Between 50 -100m	< 50m
Terrain elevation	> 6 m	3 – 6 m	<3 m
Vegetation	Dense with mature Forest and no erosive evidences	Well established with grass and bushes	Little or no vegetation
Coastal engineering structures	Absence of coastal structures	Small or little significant structures	Presence of seawalls, groins, breakwaters, jetties, etc.
Occupation rate	< 30%	Between 30 – 70%	> 70%
Soil permeability	Permeable with little or no occupation	Moderate permeability due to occupation/urbanization	Permeability seriously affected with well developed urban settlement

and a new indicator was added to the table (occupation rate).

The used variables are beach profile, shoreline position, dune field configuration, offshore settings and presence of rivers and/or inlets, terrain elevation, vegetation, coastal engineering structures, occupation rate and soil permeability. Parameters applied to classify the indicators in low, moderate and high risk are described in Table 1. Some of the indicators are discussed here and a full description is given by Bush et al. (1999).

Beach Profile and Shoreline Position

It is known that beach profiles vary continuously along the year being directly related to the sediment supply and incoming wave characteristics. Changes are also influenced by natural agents like sea-level rise or storm surges, and/or anthropic activities like occupation in the sediment sources and dam constructions.

The analysis of shoreline position has been made through remote sensing techniques, geoprocessing tools and available field data. The analyses were carried out based on satellite images and aerial photographs which are captured in an instant in space and time. However, they supply important information on coastal evolution (White & El Asmar, 1999; Plaziat & Augustinos, 2004).

The images (1962, 1977 and 1994) and field data collected in 2006 (Nuber, 2008) used to evaluate the proposed indicators are available at IO-USP. Additionally, the image used to elaborate the maps is available online at the Instituto Nacional de Pesquisas Espaciais' website. The file number 2796-12 is a digital aerial photograph with resolution of 1 m. The geoprocessing work was built in IDRISI, ArcGIS 9.3 and AutoCAD Map 2010. The geoprocessing tools were applied to provide information on the coastline variation over approximately 40 years.

Coastal Engineering Structures

The construction of coastal structures is carried out to control beach erosion, enlarge beach sediment volume and to protect urban infrastructure near the coast. The type of protection structure is defined as a function of the severity level of the erosion, nonetheless, there are social (e.g.: buildings, urban structures), economical (e.g.: tourism and leisure) and environmental (e.g.: shoreline stability and coastal ecosystems) demands that are taken into account.

In that sense, this work considers the coastal engineering structures indicator as absence of coastal structures, small or little significant structures, and the presence of seawalls, groins, etc.; as low to high risk, respectively.

Occupation Rate

For the occupation rate estimates, a limited area of interest with a constant distance landwards from the waterline has been defined considering the extension of the beach and the type of land use. Thereby, based on visual observations, a distance of 500 m has been defined. In this study edifications and roads have been defined since they represent the most expressive form of land use in Massaguaçú. However, other variables can also be taken into account. The occupation rate is here defined as the total area of all the urban structures and the difference between the percentile of occupied area and the total area.

RESULTS

Each sector was defined as a function of its basic characteristics. The coastline changes obtained from the geoprocessing analyses confirmed the tendencies obtained by Nuber (2008), with accretion events from 1962 until 1994 and an inverse trend after the mid 90's. However, it is important to understand that those variations do not present a linear pattern in space and time, and they can be strongly affected by anthropic agents.

The sector 1 (Figure 2) is an area of recent urban growth towards Massaguaçú River with gravel roads and horizontal and less dense occupation, mostly related to holiday homes. The occupation rate is of about 24%, the smallest rate of the analysed stretch of coast. This is a residential area with no apparent urban planning. Streets are narrow without an organized pattern, resulting in moderate soil permeability. Despite being unpaved, they restrain the surface flux, being the likely reason for

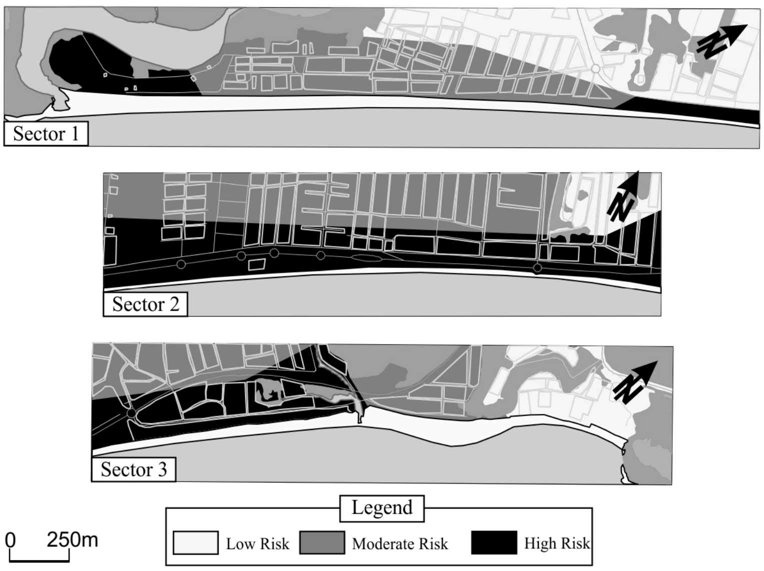

Figure 2. Results of risk assessment along the study area.

inundations during rainy seasons. The Capricórnio river inlet is usually closed by a thin sand barrier that develops due to longshore transport. During storms, overwash processes can breach the barrier opening the inlet.

The average beach profile in this sector is of 62 m and the coastline accreted 4.4 m.yr^{-1} (Nuber, 2008). There is no evidence of dunes and the occupation is in the backshore zone. The site does not present natural structures to minimize the wave attack. The terrain elevation is between 2 and 2.5 m and there is little vegetation that is being removed for construction of houses on the seaside limit and there are no coastal engineering structures.

The risk percentile has been defined as 40 %. This sector has no highways and infrastructure to receive an intense tourism flux being the most preserved area on this coast. The west side is the last area for urban expansion of Massaguaçú and new properties are being build there even close to the riverbanks. The risk increases in the central area and decreases towards sector 2.

The central part of Massaguaçú concentrates the urban settlement driven by the presence of the Rio-Santos highway, which is responsible for a significant flux of vehicles (Figure 2).

The occupation rate is 48% and, although the edifications are located about 70 m far from the high tide line, the road is only 25 m away, running between the beach and the buildings. The road runs parallel to the shoreline along the central and eastern part of Massaguaçú. This sector has no dunes or backshore, moreover the sediment sources are compromised and the coastline is retreating at a rate of about 1.5 to 2 m.yr^{-1}. The average extension of the beach profile is of 50 m, though stretches with less than 20 m are observed, where the run-up gets close to the lower limit of the road.

During high energy events, the waves reach the road causing the destruction of its seaward edges, leading the local authorities to set small man-made structures, like sandbags parallel to the beach in order to mitigate the wave attack. Furthermore, the maximum terrain elevation is 2 m with no vegetation contributing to the current erosive process in this sector. There are no rivers or inlets in this sector and it is not influenced by the small rivers that reach the other sectors. The soil permeability is mostly influenced by the highway because the other roads in its vicinity are unpaved.

This sector presents visible erosion and its current situation cooperates to the development of this process. The percentile of risk was of 50%. This area also presents critical erosion hotspots (Nuber, 2008).

The occupation in sector 3 is restrained by the proximity with the Serra do Mar hills; nevertheless, the occupation rate was of 36%. As a result of the sedimentation process in the west of Massaguaçú, the Bracuí River inlet has a tendency to close, generating inundations landwards translated in economic and social damages. Therefore, its mouth is kept artificially open, especially during the rainy seasons.

The shoreline has been accreting 3.5 m.yr^{-1} and the beach profile is 59 m long in average. There is no important sediment source to the beach and the occupation represents potential interruption of sediment supply. There are no dunes and the elevation is between 1.5 to 2.5 m and higher due to the Serra do Mar hills. Regarding to the vegetation, it is inexistent on the sea level, but presents Mata Atlântica forest characteristics on the mountains landwards. The soil permeability is moderate due to the occupation.

This sector shows 40% of moderate risk. The occupancy in this area is recent and limited by the landform in the east. The deviation in the road also contributes to the reduced amount of houses in sector 3 (Figure 2).

DISCUSSIONS

In order to provide reliable information on coastal issues, long-term monitoring is strongly indicated. However, actions to prevent or minimize coastal erosion are usually reached through short-term solutions, like coastal structures, which in many cases result in changes to the beach profile, affecting seabathing and the scenic beauty of the beach. In this sense, defining coastal risks to erosive processes is a remarkable tool for coastal management.

The method presented here is simple and of fast application giving information that allows guiding further work and interventions at different work scales. The application may be helpful do define the land use of several sectors of a beach.

However, it is suggested to insert more indicators to encompass a larger number of physical variables. In respect to the human variables, inserting data of socioeconomic profile of families located in the coastal zone is strongly recommended. These data may also be used for defining a risk index.

Parts of Massaguaçú beach are under severe erosion and the type of occupancy, parallel to the beach in sector 2, causes the reduction in the area for sediment exchange. The causes of the erosion in this sector are not well understood yet. But the role of the occupation is paramount to the local morphodynamics. Sectors 1 and 3 are accreting during the last decades, however not resulting in low risk to erosion, since other processes are acting in these areas. There are no important sediment sources in Caraguatatuba and the river contribution is not relevant due to the proximity of the Serra do Mar mountain chain, leaving them with a reduced drainage basin.

CONCLUSIONS

Massaguaçú beach is classified as being of moderate risk at its north and south limits and high risk in the central area. The evaluation by the indicators was coherent with the currently observed situation on the coast. It is an interesting tool for future interventions in respect of urban infrastructure.

The prevailing occupation in the region is horizontal with houses with a maximum of two floors, but the real estate speculation indicates a strong tendency to plan condominiums and buildings with about seven or more floors. To avoid the socioeconomic damage caused by erosion, the occupation process, with vertical trends, should consider the sediment budget behavior and erosive trends in Massaguaçú.

Urban planning is strongly indicated in order to minimize the negative impacts. These indicators are useful to provide important information on the most susceptible areas to erosive processes.

ACKNOWLEDGEMENTS

The authors are thankful to Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for the authors fellowships grants, and to Fundação de Amparo à Pesquisa do Estado de São Paulo (Fapesp) for the financial support through the VULSPE Project (ref. 2009/52564-0).

LITERATURE CITED

Airoldi, L; Abbiati, M.; Beck, M.W.; Hawkins, S.J.; Jonsson, P.R.; Martin, D.; Moschella, P.S.; Sundelöf, A.; Thompson, R.C. and Aberg, P., 2005. An ecological perspective on the deployment and design of low-crested and other hard coastal defence structures. *Coastal Engineering*, 52 1073– 1087.

Bird, E.C.F., 2008. *Coastal Geomorphology: An introduction*. Wiley and Sons, Chichester. 411 pp.

Boruff, B.J.; Emrich, C. and Cutter, S.L., 2005. Erosion Hazard Vulnerability of US Coastal Counties. *Journal of Coastal Research*, 21 (5) 932-942.

Bush, D.M.; Neal, J.W.; Young, R.S. and Pilkey, O.H. 1999. Utilization of geoindicators for rapid assessment of coastal-hazard risk and mitigation. *Ocean & Coastal Management*. 42, 647-670.

Cai, F.; Su, X.; Liu, J.; Li, B. and Lei, G. 2009. Coastal erosion in China under the condition of global climate change and measures for its prevention. *Progress in Natural Science*. 19, 415-416.

Cooper, J.A.G. and McKenna, J. 2008. Social justice in coastal erosion management: the temporal and spatial dimensions. *Geoforum*, 39, 294-306.

Correa, I. D. and Gonzalez, J.G, 2000. Coastal erosion and village relocation: a Colombian case study. *Ocean & Coastal Management*. 43, 51-64.

Dal Cin, R. and Simeoni, U. A model for determining the classification, vulnerability and risk in the southern coastal zone of the Marche (Italy). *Journal of Coastal Research*. 10 (1), 18-29.

Dornbusch, U.; Robinson, D.A.; Williams, R.B.G. and Moses, C.A. 2007. Chalk shore platform erosion in the vicinity of sea defense structures and the impact of construction methods. *Coastal Engineering*. 54, 801-810.

Fiore, M.M.E.; D'Onofrio, E.E.; Pousa J.L.; Schnack, E.J. and Bértola, G.R. Storm surges and coastal impacts at Mar del Plata, Argentina. *Continental Shelf Research*. 29, 1643-1649.

Federici, P.R. and Rodolfi, G. 2001. Rapid shoreline retreat along the Esmeraldas coast, Ecuador: natural and man-induced processes. *Journal of Coastal Conservation*. 7, 163-170.

Melloul, A. and Collin M. 2009. Key natural and anthropogenic parameters enhancing the effect of sea level rise: the case of Israel's Mediterranean coast. *Ocean & Coastal Management*. 52, 39-46.

Meur-Férec, C.; Deboudt, P. and Morel, V. 2008. Coastal risk in France: an integrated method for evaluating vulnerability. *Journal of Coastal Research*. 24 (2B) 178-189.

Nuber, E., 2008. Evolução morfológica e sedimentológica do arco praial de Massaguaçú, Litoral Norte de São Paulo. São Paulo, Brazil: Universidade de São Paulo, Master's thesis, 129p.

Pianca, C.; Mazzini, P.L. and Siegle, E. 2010. Brazilian offshore wave climate based on NWW3 reanalysis. *Brazilian Journal of Oceanography*, 58(1), 53-70.

Plaziat, J.C. and Augustinus, P.G.E.F. 2004. Evolution of progradation/erosion along the French Guiana mangrove coast: a comparison of mapped shorelines since the 18th century with Holocene data. Mar*ine Geolog*y. 208, 127-143.

Small, C. and Nicholls, R.J. 2003. A global analysis of human settlement in coastal zones. *Journal of Coastal Research*. 19 (3), 584-599.

Sousa, P.H.G.O.; Carvalho, D.A.P. and Pinheiro, L.S. 2008. A costa de Paracuru: turismo, ocupação e perfil do usuário. *Revista da Gestão Costeira Integrada*. 8 (2), 247-258.

Srinivasalu, S; Thangadurai, N.; Switzer, A.D.; Ram Mohan, V. and Ayyamperumal, T. 2007. Erosion and sedimentation on Kalpakkam (N Tamil Nadu, India) from the 26th December 2004 tsunami. *Marine Geology*. 240, 65-75.

Stanica, A.; Dan, S. and Ungureanu, V.G. 2007.Coastal changes at the Sulina mouth if the Danube river as a result of human activities. *Marine Pollution Bulletin*. 55, 555-563.

Thieler, E.R. and Hammar-Klose, E.S. 1999. National assessment of coastal vulnerability to sea-level rise, preliminary results for the U.S. Atlantic Coast: U.S. Geological Survey, Open-File Report 99-593, 1 sheet. (Available online at: http://pubs.usgs.gov/of/of99-593/)

White K. and El Asmar, H.M. 1999. Monitoring changing position of coastlines using Thematic Mapper imagery, an example from the Nile Delta. *Geomorphology*. 29, 93-105.

Xue, Z.; Feng, A.; Yin, P. and Xia, D.. 2009. Coastal erosion induced by human activities: a northwest Bohai Sea case study. *Journal of Coastal Research*. 25(3), 723-733.