

Coastline changes near the “*Maranhão - Ponta da Madeira*” Port Complex, Brazil

Alterações costeiras perto do Complexo Portuário do Maranhão - Ponta da Madeira, Brasil

Luis Americo Conti¹

¹ Email: lconti@usp.br

ABSTRACT: This article describes changes in the shoreline near the port complex at Maranhão, Brazil, and adjacent areas. The main objective was to evaluate the morphological changes in the study area during recent decades based on satellite remote sensing image analysis by comparing a series of eight images obtained with different sensors (Landsat, Quickbird, Geoeye, Ikonos, and Worldview 2 and 3) in the vicinity of an industrial harbor area. The shoreline was characterized by digitization and vectorization using each image, and the statistic spatial changes in the shoreline were quantified using the Digital Shoreline Analysis System. In addition, time change detection analyses were conducted in specific areas in order to establish correlations between the erosion/deposition areas with changes in vegetation and the land-cover dynamics. Throughout most of the area, the shoreline tended to remain stable during the study period. However, four specific areas exhibited variability at localized points on the shoreline, particularly areas near the port region and those adjacent to estuarine channels evidencing that the port complex has a direct influence on the shoreline behavior in a relatively stable area.

Keywords: Shoreline changes; coastal zone; GIS; Remote Sensing; Geo data-base.

RESUMO: O presente artigo descreve as alterações da linha de costa localizada junto ao complexo portuário de Maranhão, no Brasil, e às áreas adjacentes. O principal objetivo passa pela avaliação das alterações morfológicas na zona de estudo, durante as décadas mais recentes, com base em sensoriamento remoto por satélite, através da

análise de uma série de oito imagens obtidas a partir de diferentes sensores (Landsat, Quickbird, Geoeye, Ikonos, Worldview 2 e 3) na vizinhança da área portuária industrial. A linha de costa foi caracterizada por digitalização e vetorização utilizando cada uma das imagens. As mudanças espaciais foram quantificadas utilizando o Digital Shoreline Analysis System. Acresceu-se ainda, a análise e detecção das alterações temporais realizada em áreas específicas de modo a estabelecer a correlação entre as áreas de erosão/deposição com alterações na vegetação e na dinâmica de cobertura de solo. Na maioria da área analisada o solo tendeu a manter-se estável durante o período de estudo. Contudo, quatro áreas específicas exibiram variabilidade em pontos localizados junto da costa, particularmente nas áreas junto à região portuária e nas áreas adjacentes aos canais estuarinos, demonstrando que o complexo portuário tem uma influência direta no comportamento da linha de costa, numa área que é relativamente estável.

Palavras-chave: Alteração de linha de costa, Zona Costeira, GIS, Sensoriamento Remoto, Base de dados Geográfica.

1. INTRODUCTION

Using Satellite images for characterizing shore environments provides an important tool for analyzing and monitoring changes in shore areas, especially in the context of global climate change. International studies involving governmental and non-governmental organizations, such as the Intergovernmental Panel on Climate Change, Group on Earth Observations Biodiversity Observation Network, and Intergovernmental Oceanographic Commission, have emphasized that the systematization of knowledge regarding shore landscapes and ecosystems is essential for understanding climate regulation processes due to the variability in biogeochemical cycles causing the suppression and deterioration of wetland ecosystems, such as mangroves. It is particularly important to monitor areas that are susceptible to flooding and the shore erosion associated with changes in the sea level, as well as due to increases in the intensity and frequency of storm events (Michener et al., 1997; McIness et al., 2003; Woodruff et al., 2013; Arkema et al., 2013). Despite their different geomorphological configurations, the positions of shorelines and their adjacent emerged and submerged environments tend to exhibit a dynamic equilibrium between the input and output of sediments. However, engineering work and processes related to human occupation inshore environments can affect these dynamics and lead to the advance or retreat of shorelines in affected areas, thereby highlighting the importance of specific and complex environmental assessment in these regions.

In Brazil, recent works dealing with shoreline analysis have noted a clear general trend of be in condition of stability or in erosion (e.g., Muehe, 2006 Souza and Suguio, 2003; Grigio et al., 2005; Amaro et al., 2015; Conti et al., 2016 among others). Despite the overall consensus about the relationship between modern (Anthropocene) climate change and sea level rise

(Nicholls and Cazenave, 2010), it is not quite clear what exactly the role of the global sea level rise in local erosional events and processes. Muehe (2006 and 2010) have noticed that for most of the Brazilian coast, the main causes of local changes in shoreline can be also related to a combination of increasing of wave energy (due higher frequency and intensity of storms) and sediment deficit. In this context, the absence of long-term observations of oceanographic data and detailed altimetric maps brings a major difficulty to understand the weight of different factors contributing to the coastal variability.

Geostatistical shoreline positioning analyses using change detection methods have been employed successfully to evaluate the annual or decadal behaviors of shorelines, thereby providing important information for establishing action plans in areas undergoing erosion or accretion. According to previous research (Naik and Kunte, 2016; Pérez et al., 2013; Pupienis et al., 2013; Kinsman and Gould, 2014), quantitative studies of shorelines nearby occupied areas such as urban settlements, ports and constructions are essential for establishing management and planning policies. Thus, assessing risks and characterizing their effects in a prompt manner can facilitate forward planning in order to mitigate impacts, as well as acquiring advanced knowledge regarding the use of economic resources and the implementation of engineering work in a local environmental context (Conti and Rodrigues, 2012). The present study analyzed decadal changes to identify patterns in the shoreline and shore environment near the port of São Luiz, Maranhão, Brazil, in order to determine changing morphosedimentary trends in this environment.

2. STUDYAREA

The Maranhão port complex is located on the western shore of São Luís Island in São Marcos Bay (Figure 1). The port is the second largest in Latin America and one of the largest throughout the world in terms of cargo

traffic, with more than 85 million tons transported in 2006, which corresponds to over 15% of the annual port traffic in Brazil. This complex comprises the port complex at Ponta da Madeira, the port of Itaqui and the port of Alumar. The access channel of the port complex at Maranhão is the longest, widest, and deepest buoyed access channel among the port areas in Brazil. It mostly occupies the continental shelf of Maranhão (Gulf of Maranhão) and the remaining area is located in São Marcos Bay. The width of the channel along most of its length is 1,000 m and the minimum width is 500 m in specific areas (CVRD, 2001).

The region is subjected to inner shelf hydrodynamic processes, but tidal variations mainly govern the circulation dynamics of the currents, where the wind regime and incidence of waves contribute to episodic and local deviations in the circulation caused by the tides. In this region, the waves produced by local winds can reach up to 1.10 m in height with periods of 6 s in the basin and nearby areas and the direction of local winds is mainly northeasterly with a frequency of 25% (CVRD, 1997). The tide is typically semidiurnal and based on observations at Pier I, the highest astronomical tide values are 6.40 m. In the port area of Maranhão, the tidal currents generally have axial and alternating directions, where they are sinusoidal relative to variations in intensity

producing overall ebb dominated strong currents that reach up to 3 m/s on ebb spring tides. The maximum speeds occur approximately at half-tide and the minimum speeds occur under conditions approaching the high and low tides. Superficial sediments are composed by sand, covering the entire subaqueous dunes area. The dominant fraction is composed by fine to very fine sand (> 90%) (Samaritano et al., 2013).

According to numerical modeling studies (e.g., Amaral and Alfredini, 2010), modifications of groynes have allowed greater bottom sediment drift in the region of the piers, thereby generating a silting/erosive alternating pattern, which is typical of areas with high speed currents, where the oscillation is greater at the bottom. This pattern was not observed with the original groynes, thereby demonstrating that their modification caused the current speed to decrease and this led to increasing sedimentation processes. The modifications of groynes allowed the current speed to increase outside the sheltered region, which enhanced the efficiency of partial cleansing near the bottom (Garcia, 2004).

3. MATERIALS AND METHODS

Detailed monitoring of the decadal/multiannual behavior of shorelines is a conceptual and technical challenge. In conceptual terms, the main issue is associated with

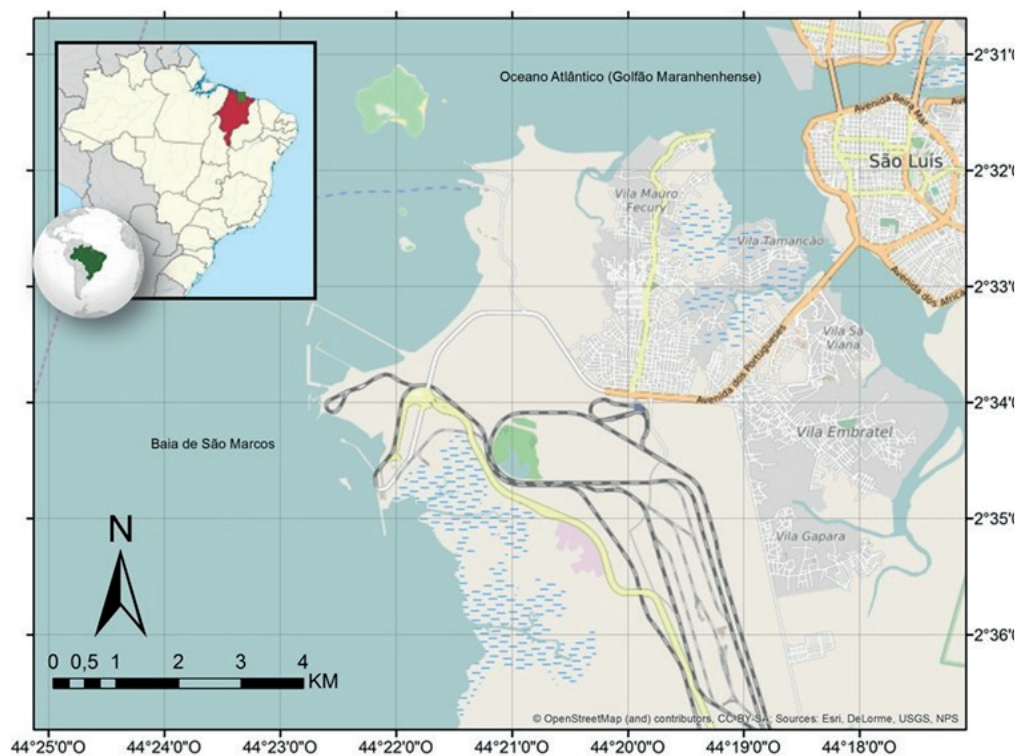


Figure 1. Location of the study area - Maranhão port complex.

Figura 1. Localização da área de estudo - complexo portuário do Maranhão.

the definition of the “shoreline” itself and within the context of dynamic analysis, the wider definition of a “shoreline zone” has been employed, which corresponds to the fringe between the extreme limit of the syzygy equinoctial low tides and the beginning of the vegetation colonization region (Philips, 1996). Inside this area, it is possible to determine a series of shorelines, where each is defined by a specific criterion and by an extraction and analysis method. Moore et al.. (2012) established different criteria for the definition of shoreline positioning methods in order to determine the occurrence of erosion/accretion processes. Methods that are purely visual (i.e., that do not consider the spectral characteristics of bodies of water/ sediment/vegetation) usually consider the sand/vegetation or dry sand/wet sand transition line as the basis for the shoreline’s position. In specific cases, the water/soil contact zone may be extremely dynamic due to high frequency processes (waves and tides).

According to previous studies (Alesheikh et al., 2007; Boak and Turner, 2005; Maiti and Bhattacharya, 2009), each method employed to determine the shoreline position (vegetation line, debris line, or waterline) also implies the use of different image processing methods when the spectral aspects of satellite images are established. For instance, in the case of waterline determination, masking using the infrared (IR) band is more appropriate because it clearly differentiates between water and soil, whereas the vegetation line tends to be determined better by visual (manual) extraction via the fusion of bands in the visible and IR ranges. Foody et al. (2005) overpass the definition of physical shoreline using Fuzzy logic to classify the pixels as probability of “land” or “water”.

In the present study, the vegetation line was used as a reference for the shoreline because the main aim of this study was to establish multiannual and decadal patterns, and the behavior of the vegetation line tends to exhibit more robust trends since it shows less variability in time and space. In addition, in a tropical region, colonization by various species tends to occur rapidly, which is compatible with the time resolution of image acquisition. However, using the vegetation line as the basis for the analysis demands a careful interpretation given that the behavior of vegetation can differ in erosion (more direct) and accretion (depending on the colonization time) patterns.

The spatial resolution of high-resolution satellite images is more suitable for the analysis of shoreline variability, but satellites only started to provide commercial images to the market during the first decade of the 21st century, thereby making detailed analyses at this level impractical in previous years. Shoreline variability control usually tends to require a higher time amplitude, so the combined

use of medium resolution images (typically 10–40 m per pixel) is necessary. In this work we used high and medium resolution images were used, as shown in Table 1.

Table 1. Images processed to characterize the shoreline.

Tabela 1 – Imagens processadas para caracterizar a linha de costa.

Date of image acquisition	Satellite	Sensor	Spatial resolution (m)
1986-07-19	Landsat 7	TM	30
1995-07-12	Landsat 7	TM	30
2000-06-07	Landsat 7	TM	30
2005-06-21	Landsat 7	TM	30
2007-11-23	Quickbird II	BGIS	0.6
2009-02-30	IKONOS	Ik-2	1
2010-10-22	GEOEYE	Geoeye-1	0.41
2012-22-03	WORLDVIEW2	WVII	0.46
2015-12-07	WORLDVIEW2	WVII	0.46

The question of using images with different resolution can be an issue due to the inherent error of positioning the shoreline in relation to different pixel sizes. These questions were addressed through studies of accuracy assessment, spatial uncertainty and resampling techniques (Taha and Elbeih, 2010; Shah, 2011; Pardo-Pascual, 2012; Caballer, 2016). Marfai et al.. (2008) emphasized that multi sources spatial data analysis can be considered a valid tool of analyses regarding lack of homogeneous data as long as the interpretation is consistent with the limitations of the shoreline extraction models. Since the area is dominated by the intercalation of constructed shorelines associated to the port structures, (e.g. port quay walls and bulkheads) these fixed features were used to calibrate the position of the shoreline since they remained unchanged along the period of analysis. We have established that the accuracy of the method was based on the maximum variability induced by the differences in shoreline position in such fixed structures (figure 2).

All of the images were associated with a georeferenced database and they were processed according to previously described methods (Farias and Maia, 2010; Conti and Rodrigues, 2012; Marino and Freire, 2013). All of the images were geocoded according to a series of control samples at specific points in order to obtain their references with respect to the same database. The Worldview 2 image was used as the basis for this process because it was obtained at the ortho rectification correction level.

After digitizing the multi-temporal shoreline vector files for the study region, a project was created using Digital Shoreline Analysis System (DSAS), which is an application associated with the ARCGIS program (Thieler et al., 2009). DSAS creates quantitative parameters

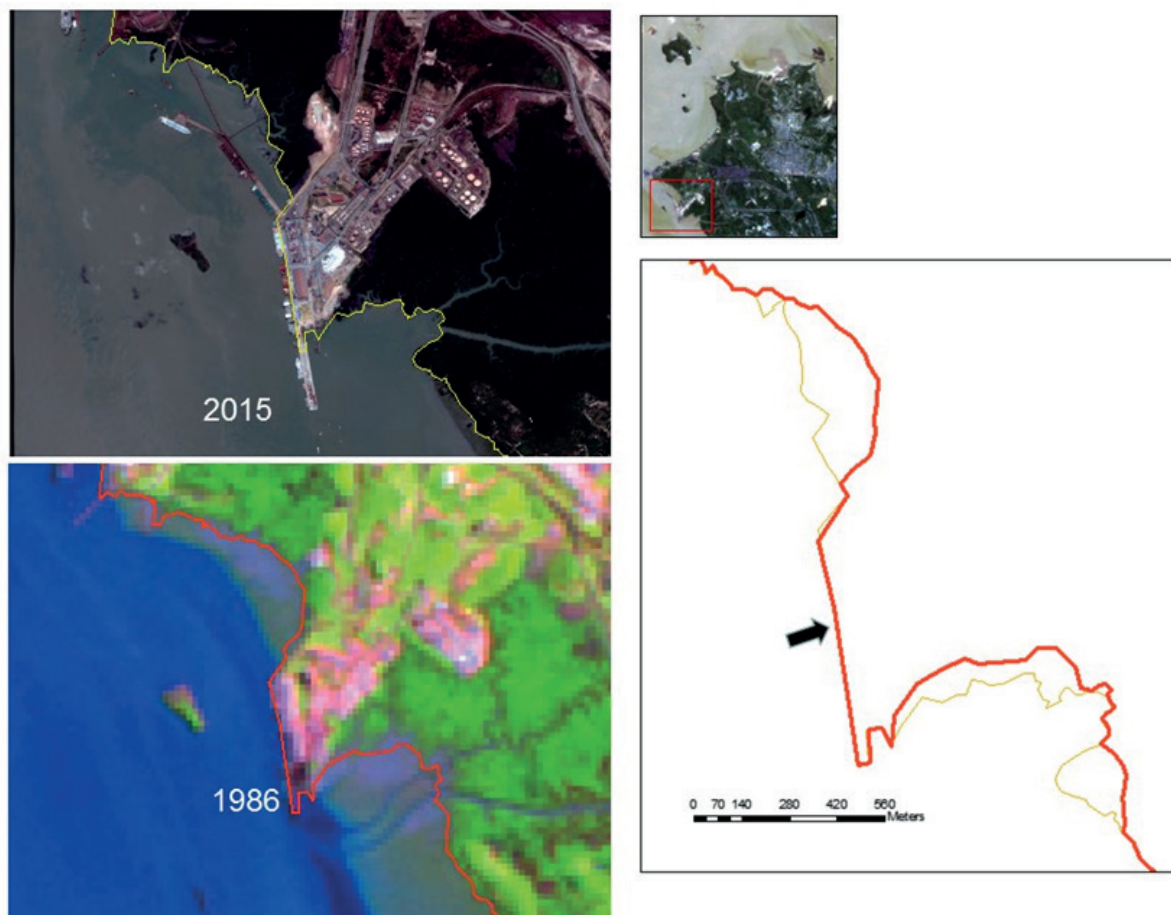


Figure 2 – Example of fixed structure (port quay wall) as guide to determine the shoreline position (indicated by the arrow). The image shows the Landsat (30 m pixel) image of 1996 and a WorldView III Image (0,5 m pixel) of 2015.

Figura 2 - Exemplo de uma estrutura fixa (cais de acostagem portuário) usada como referência para determinar a posição da linha de costa (indicada pela seta). A imagem mostra a imagem Landsat (30 m pixel) de 1996 e uma imagem do WorldView III (0,5 m pixel) de 2015.

regarding changes in a shoreline by generating orthogonal transects relative to a baseline, which are determined by the user in a defined space, before calculating the rates change using different statistical methods, and these results are then converted into a relational table. For the study area, 184 transects were generated with an average distance of 100 m between them.

The DSAS can generate different statistical analysis for each transect to calculate rates of changes locally. In order to determine the historical variation in this study we calculated 4 statistical approaches: 1 – EPR (End Point Rate) is calculated by dividing the distance of total shoreline movement between the earliest and latest measurements providing an annualized rate of change: 2- SCE (shoreline change envelop) measure of the total change in shoreline movement considering all available shoreline positions. 3- LRR (linear regression rate) determines a rate-of-change statistic by fitting a least square regression to all shorelines and 4- NSM (net shoreline movement) reports the distance between the oldest and the youngest shorelines (Sheik,

2011, Ford, 2013; Oyedotun, 2014).

Analyzing time series of satellite images allowed two different work scales to be derived from the resolution of the images acquired for the area and for the period with imaging coverage. Based on the analysis of high-resolution images, a detail scale with a pixel size less than 1 m was obtained with greater periodicity (only available from 2007). This analysis level focused on the determination of detailed variations, especially in terms of the vegetation colonization trends, which indicated deposition processes. The other working scale was used for long-term analyses based on decadal imaging, mainly based on Landsat images with a pixel size equal to or greater than 30 m, which allowed the determination of more long-lasting trends with greater dimensions, as shown by the DSAS analyses.

It should be emphasized that at this scale with a reference pixel of 30 m, small variations in the shoreline position (smaller than 50 m) could not be characterized definitively given the variability in the imaging position. However,

shoreline variations of this order can be important in practical terms, especially those near structures and constructions. Thus, detailed analyses based on the interpretation of high-resolution images allowed the identification of small variability areas and specific trends. However, these analyses did not facilitate assessments of decadal variability because this type of imaging only became available in the early 21st century. Long-term analyses of the study area based on Landsat images demonstrated the relative stability of the shoreline's behavior throughout the whole area. In contrast to many other shoreline areas in Brazil, particularly those in the north/northeast regions, no large-scale trends in terms of shoreline changes (i.e., erosion/deposition processes) were

observed according to the temporal and spatial analyses of the images. These findings were supported by the trend analyses, where characteristic deposition/erosion areas were found only in a few locations, i.e., effective shoreline advance or retreat occurred in only four areas.

4. RESULTS AND DISCUSSION

Figure 3 shows the study region, including the shorelines and transects generated by the DSAS software. The marked lines indicate areas that exhibited effective shoreline variations during the study period (1986 to 2012), where four areas underwent effective changes in their shoreline position (i.e., due to erosive and/or depositional processes).

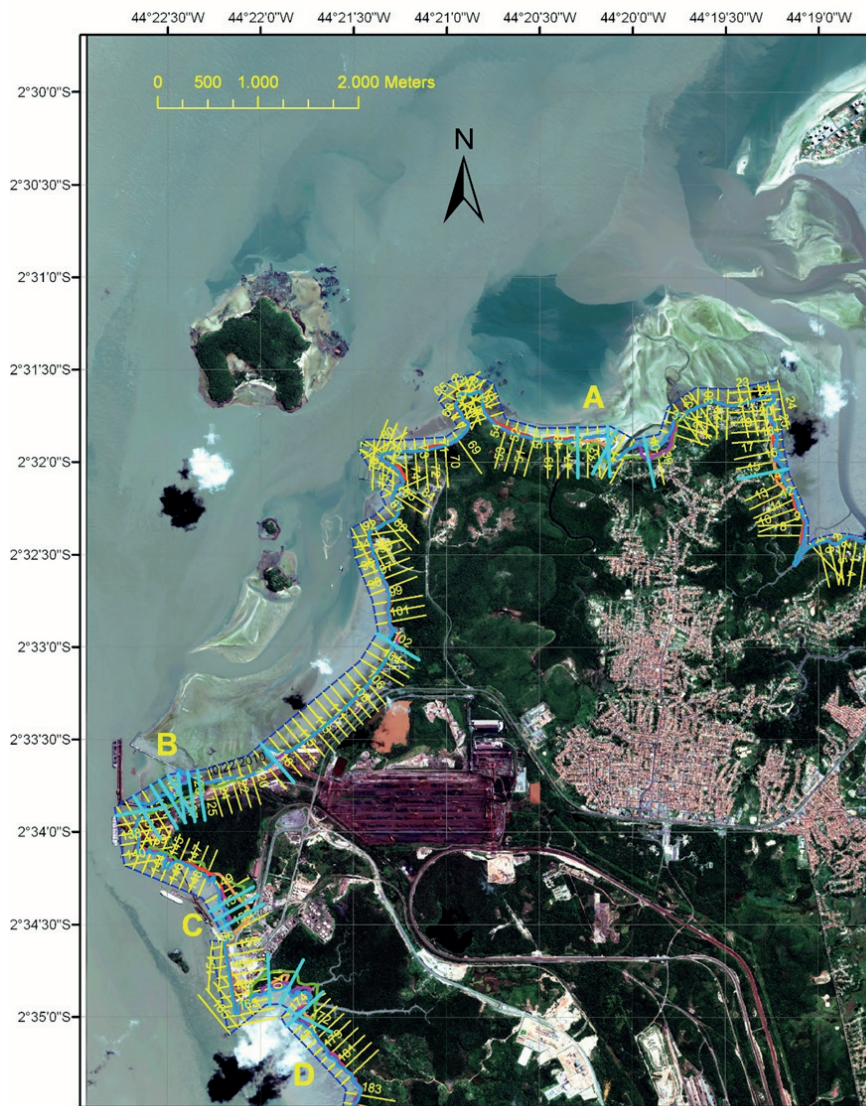


Figure 3 – Digitized shorelines in the study area and transects generated using DSAS software. The highlighted transects represent areas with higher variation in shoreline position.

Figura 3 – Linhas de costa digitalizadas na área de estudo e transectos gerados utilizando o software DSAS. Os transectos destacados representam áreas com maior variação na posição da linha de costa.

Figure 4 shows details of the regions with significant changes indicated in Figure 3 . The first area was located in the northern part of the study area near Guia beach (identified as zone “A” in Figure 4A). In this region, the shoreline change was variable with erosive and depositional processes, which were probably associated with the dynamic variability of the adjacent fluvial channel combined with the inner shelf hydrodynamics. The northeast part of the area clearly exhibited a depositional trend, which was indicated by colonization by vegetation in the deposition areas as well as in the area opposite the channel where growth occurred,

whereas the sand area connected to the estuary retreated, especially after 2007. This variability appeared to be restricted to erosion and deposition patterns at the mouth of the channel, and no overall trend was associated with other parts of the study area. The total change in the area shown in Figure 5, representing the parameter SCE (shoreline change envelope) indicates that the areas with the highest variability were adjacent to the sandbar at the left of the mouth of the channel (transects 43, 44, and 45). However, this change did not follow a clear trend and there were periods of advance and retreat, which are typical of estuarine morphosedimentary dynamics.

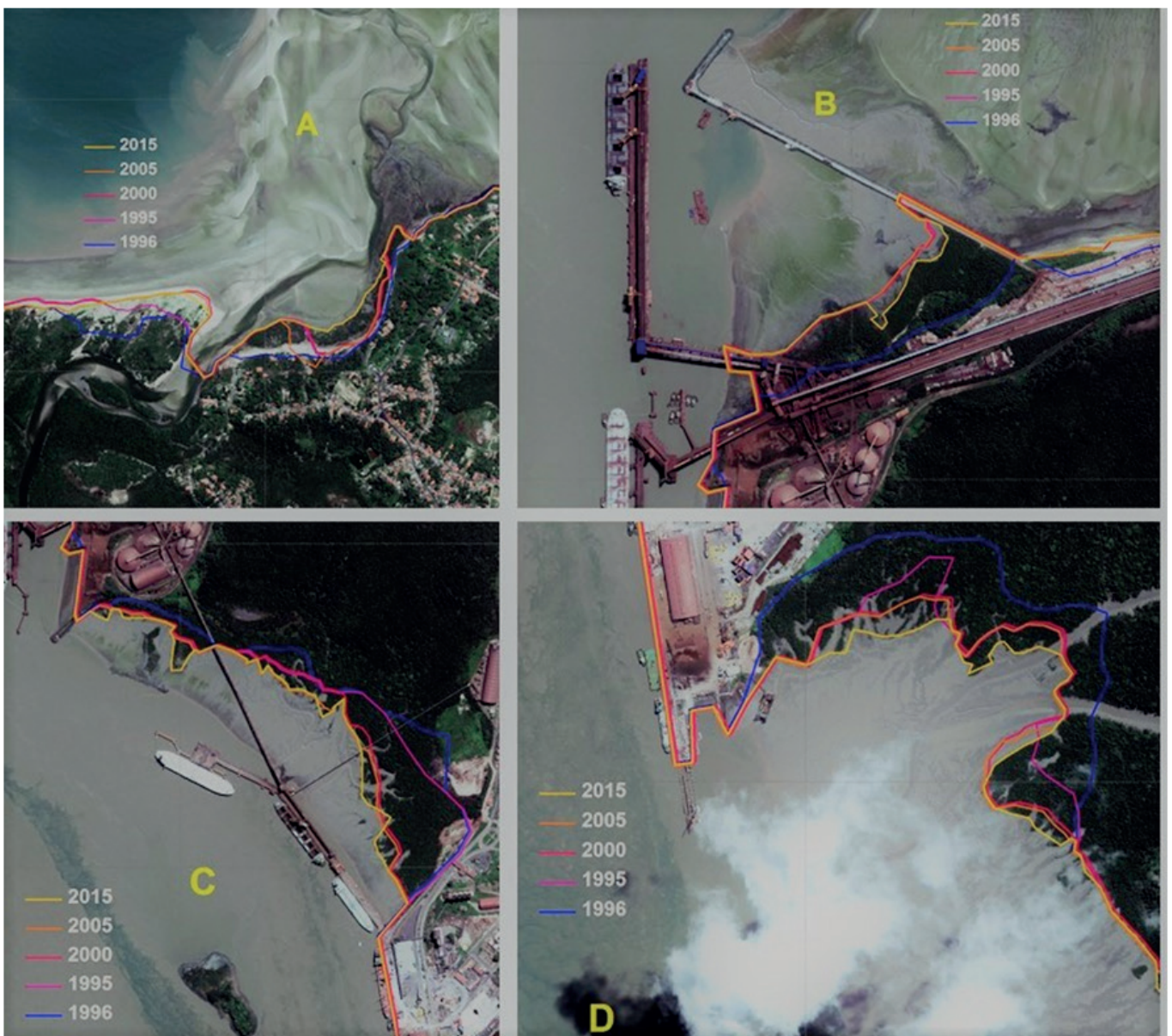


Figure 4 – Details of the areas with significant shoreline changes.

Figura 4 – Pormenores das áreas com mudanças significativas na linha de costa.

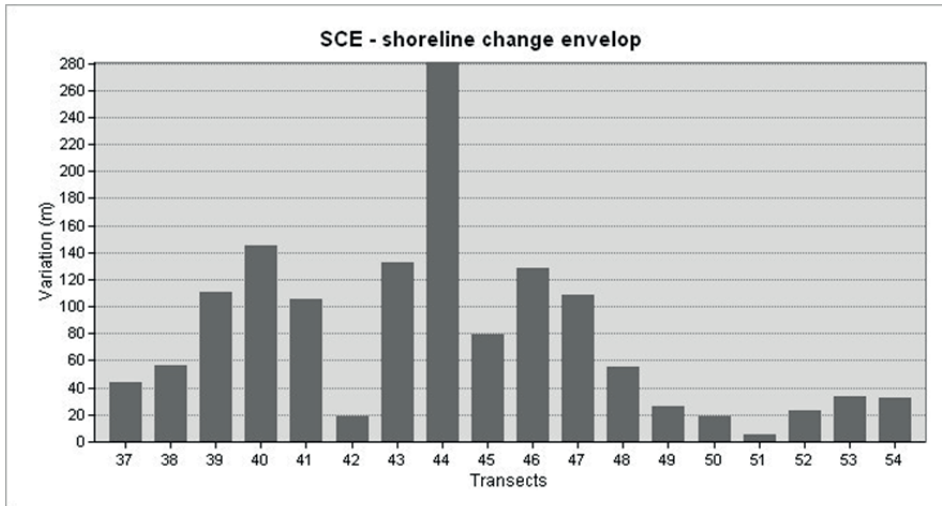


Figure 5 – Shoreline change Envelope Rates between 1986 and 2015 in the Area “A” (as indicated in Figure 4).

Figura 5 – Taxas de alteração da envolvente da linha de costa entre 1986 e 2015 na Área “A” (conforme indicado na Figura 4).

A second area with changes was identified by the DSAS analysis in the northern region of the port terminal at Ponta da Madeira, where the presence of a pier structure appeared to control the sedimentary regime of the area and an intense deposition process occurred behind this pier (Figure 4B). Figure 6 shows the calculated EPR (end point rate) for each transect in the area showing that the accretion process was relatively continuous with a rate of up to 9 m per year, but the shoreline position indicates that growth occurred between 1986 and 2005, and it remained relatively stable subsequently.

A similar change was found in the southern part of the

port terminal at region “C” in Figure 7. There was a typical depositional area between Ponta da Madeira and Itaqui Port, where the accretion process mainly affected the southern area, as shown by transects 149 to 152 observed from the NSM parameter. In this region, the accretion process covered a length of up to 260 m.

Finally, among the areas identified as susceptible to shoreline change, region “D” (Figure 8) exhibited the highest accretionary trend with more than as indicated by transects 168 to 173 in Figure 4D, and similar to area C, this trend was more evident between 1986 and 1995, with only local changes subsequently.

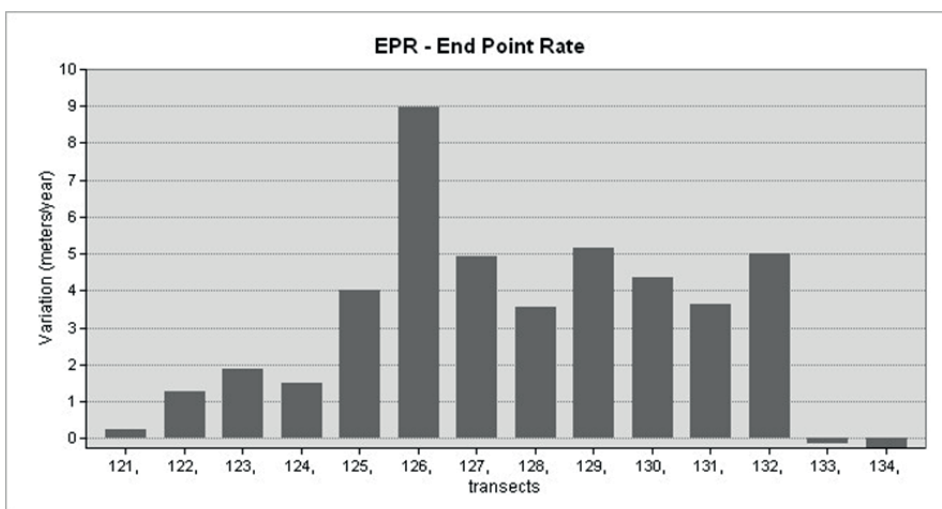


Figure 6 – End Point Rates between 1986 and 2015 in the Area “B” (as indicated in Figure 4).

Figura 6 – Taxas de variação horizontal entre 1986 e 2015 na Área “B” (conforme indicado na Figura 4).

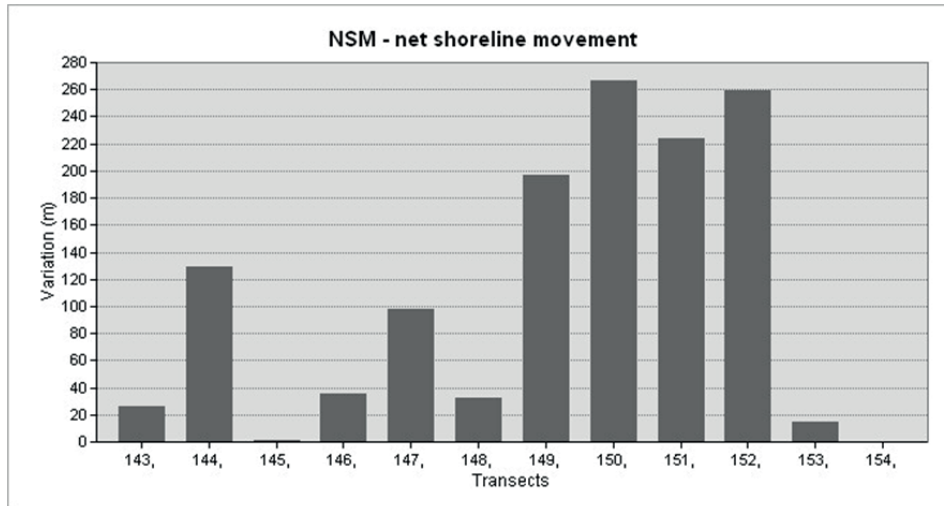


Figure 7 – Net shoreline movement rates between 1986 and 2015 in the Area “C” (as indicated in Figure 4).

Figura 7 – Taxas líquidas de movimentação da linha costeira entre 1986 e 2015 na Área “C” (conforme indicado na Figura 4).

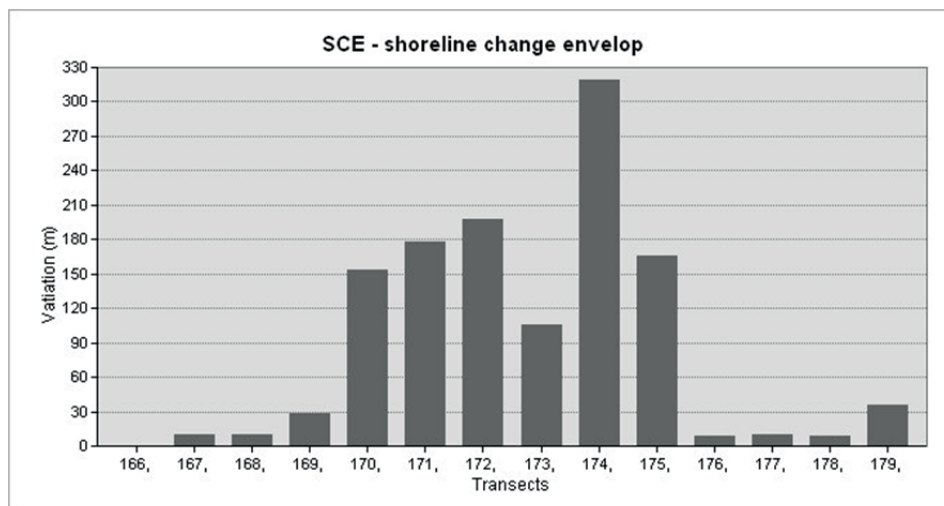


Figure 8 – Shoreline change Envelope Rates between 1986 and 2015 in the Area “D” (as indicated in Figure 4).

Figura 8 – Taxas de alteração da envolvente da linha de costa entre 1986 e 2015 na Área “D” (conforme indicado na Figura 4).

Shoreline variation analyses using the DSAS method showed that most of the study area exhibited little or no shoreline variability during the three-decade period, which was mainly attributable to the shoreline engineering via containment and/or land reclamation work that stabilized the shore. Even in the areas that were clearly dominated by depositional processes according to mangrove vegetation and sandbanks, there was no clear evidence of important sedimentary processes associated with the regional dynamics. The depositional areas in the study region were related to structures built

in the port complex (as shown by Garcia, 2004) and they exhibited constant growth trends. Figure 9 shows a linear regression of the shoreline variability in all the study transects (LRR). Among the four zones with depositional trends, three were adjacent to containment structures connected to the port complex, which determined the sediment accumulation process. Only one area apparently exhibited natural variability: a small region in the northeast of the study area (near mangrove in the Vila Nova district, which was not analyzed in detail) and another in the Guia beach region (area A).

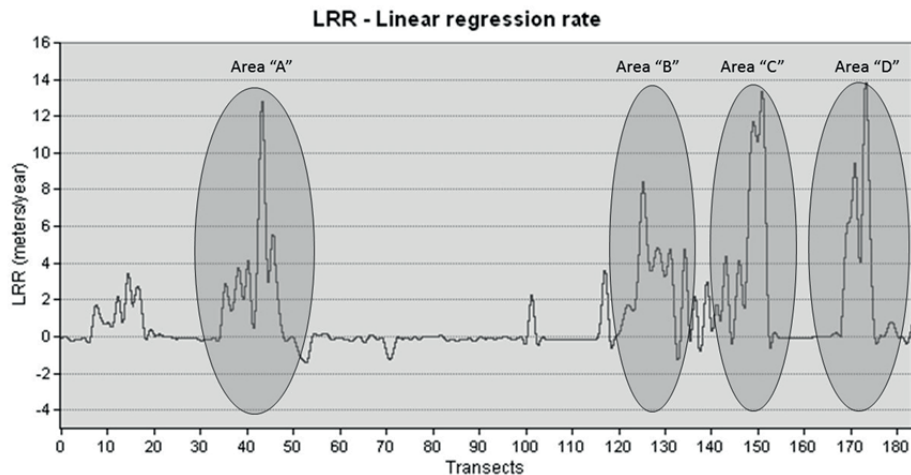


Figure 9 – Linear regression rate (LRR) of the shoreline variability between 1986 and 2015 for the entire study area.

Figura 9 – Taxa de regressão linear (LRR) da variabilidade da linha costeira entre 1986 e 2015 para toda a área de estudo.

In more detailed analyses, time change detection (TCD) techniques were also applied to the high-resolution images from 2007, 2009, 2010 and 2012 in order to identify more subtle patterns and variations at a large scale in the area of interest, but especially near the regions determined by the DSAS analyses. According to the results, accretion and colonization by vegetation tended to occur in areas near the port structures along tidal channels, which suggests that the energy in the system decreased, thereby allowing the deposition of fine sediments and the subsequent fixation of vegetation along the borders of these channels. This is shown clearly by the TCD analysis in Figure 10, based on the red–green compositions in 2007 and 2012, where the areas in red indicate colonization by vegetation and the areas with suppression of vegetation are shown in green. An extensive deforested area is visible (probably related to the expansion of the port denoted by “S” in the figure) and the growth process of the vegetation fringes is indicated by the arrows.

Similar situation occurs in “area B” near Ponta da Madeira, the differences between the images from 2007 and 2012 indicated that colonization by vegetation occurred on the shoreline, as well as in the previously mentioned areas. However, in some areas, the suppression of vegetation indicated local erosive processes. Figure 11 shows a combined image to illustrate these characteristic changes.

In terms of shoreline change rates, the values obtained in this work have a reasonable overall scaling agreement with other similar studies showing a dynamic and local conditioning for sediment budget and erosion/sedimentation regime. Although for coastal environments in Brazil, most works using DSAS methods indicated significant erosion or stability, especially for beach and mangroves, the indicating of local accretion also have been reported (Table 2).

Table 2 – Summary of publications using DSAS method to evaluate shoreline behavior.

Tabela 2 – Resumo de publicações usando o método DSAS para avaliar o comportamento da linha de costa.

Source	Region	Main Indicating process	Coastal environment	Time lapse
Busman et al. 2013	Ponta Negra - RN	Erosion	beach	1986 -1999
Oliveira et al. 2015	Casino Beach - RS	Accretion	beach	1975-2009
Marino e Freire 2013	Futuro Beach - CE	Erosion	Beach/Estuary	1972-2010
Lisboa et al. 2015	Lagoa dos Patos - RS	Erosion/ accretion	Lagoon	2004-2012
Conti, 2012	Ilha Dos Guaras- PA	Erosion/ Accretion	Estuary	1973-2011
Abreu et al. 2016	Icarai Beach - CE	Erosion	Beach	2004 -2014
Ranieri and Robrini, 2015	Salinópolis- PA	Accretion	Beach	1988 -2013
Mazzer and Dillemburg	Santa Catarina Island - SC	Erosion/ Accretion	Beach	1938-2002
Baretella and Menezes	Biguaçu Beach- SC	Erosion/ Accretion	Beach	1938 -2010
Oliveira and Albino 2014	Guarapari - ES	Erosion	Beach	1970 -2007
Gregório et al. 2017	Boa Viagem Beach - Recife - PE	Erosion	Beach	1960-2008
Santos and Bonetti, 2018	Tijucas Bay - SC	Erosion/ Accretion	Beach	1938-2015
Farias and Maia, 2010	Ceará State	Erosion/ Accretion	Beach	1958-2004
Conti et al. 2012	Cananéia Inlet - SP	Erosion/ Accretion	Beach/Inlet	1962 -2006
Duarte et al. 2018	Pecem Port- CE	Erosion/ Accretion	Beach/Harbour	2011-2014

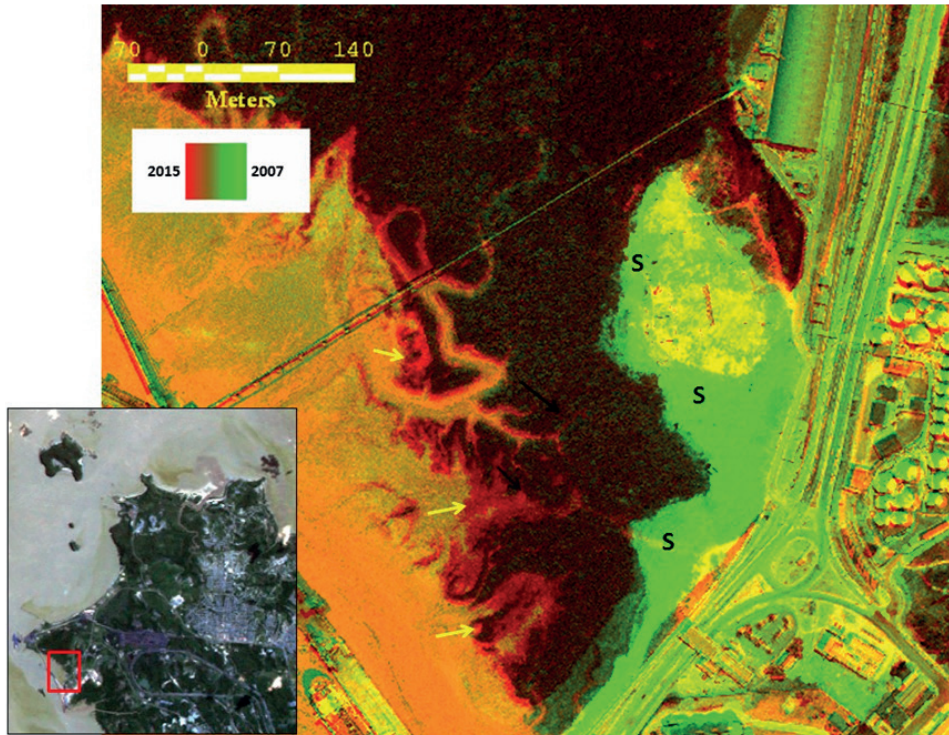


Figure 10 - Depositional trends during 2007–2015, where red (arrows in yellow) indicates colonization by vegetation and the areas with suppression of vegetation are shown in green. The port is represented by the letter “S”.

Figura 10 - Tendências de deposição durante 2007–2015, em que o vermelho (setas em amarelo) indica colonização por vegetação e as áreas com supressão de vegetação são apresentadas a verde. O porto é denotado pela letra “S”.

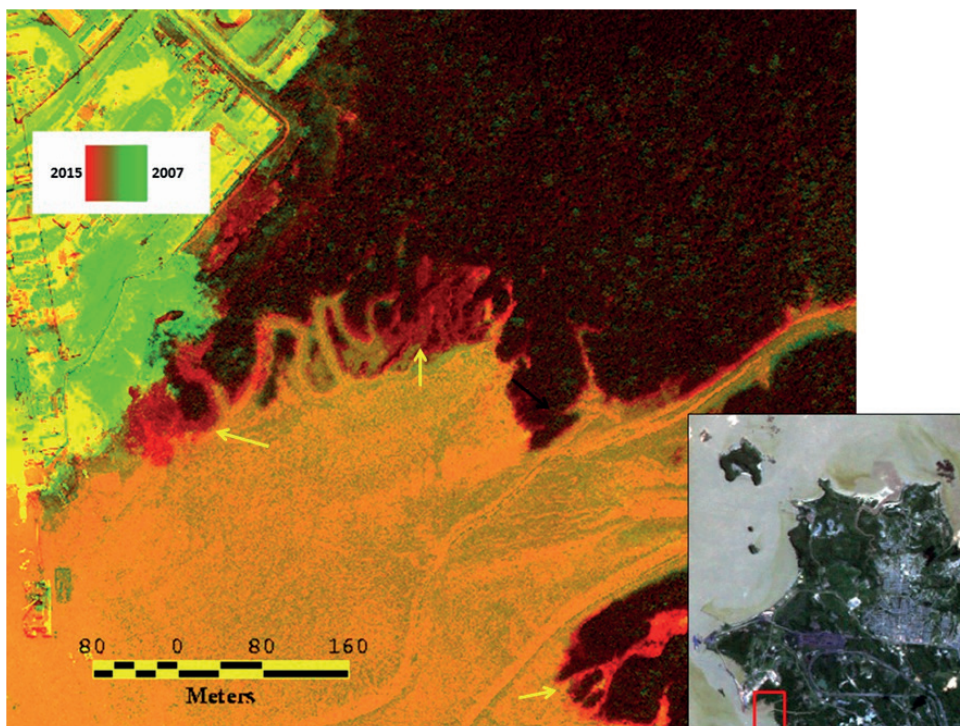


Figure 11 - Depositional trends during 2007–2015, where red indicates colonization by vegetation and the areas with suppression of vegetation are shown in green, which illustrates the depositional growth in frontal areas (yellow arrows).

Figura 11 - Tendências de deposição durante 2007–2015, em que o vermelho indica colonização por vegetação e as áreas com supressão de vegetação são apresentadas a verde, o que ilustra o crescimento deposicional em áreas frontais (setas amarelas).

CONCLUSIONS

The historical evolution and temporal morphodynamics of shoreline position and geometry are of significant importance in evaluating the spatial dynamics of the coastal system behavior (Oyedotun, 2014). Measurements and analyses of sequential series of satellite images allow trends to be established regarding the changes in a shoreline during a restricted time period (according to the time covered by satellite data). The specific dynamic events that are mainly responsible for the short- and medium-term erosive and accretionary processes on the shoreline should be determined based on specific morphodynamic characteristics and monitoring using detailed geological and geophysical analyses, such as coastal morphodynamics, bottom sediment typology analysis, detailed bathymetry, side-scan sonar, and shallow seismic and numerical modeling. These studies allow more complex and predictive results to be obtained regarding variations in the bottom topography in order to establish sediment transport trend models. In the present study, it was established the ongoing trends during the study period.

Considering that the study area (São Marcos Bay) have a quite complex interaction of natural (e.g. intense tidal currents and estuarine dynamics) and human-induced processes (port and groynes construction, urbanized processes and dredged areas) the variation of the shoreline remained relatively constant during the period of this study unlike most of Brazilian coastal zone, submitted to erosional processes. Local dynamic associated with engineering intervention and localized sediment supply effects was identified as responsible for the local variation in the shoreline. In these specific areas the shoreline have been predominately subjected to net accretion between about 100 to 200 meters whereas in 85% of the whole area the variation was below the pixel size limit detection (30m).

The use of multitemporal remote sensing analysis for map and detect shoreline position has been shown to be an appropriate tool to assess spatial variations in coastal environments. The spread of new technologies of spatial analysis and image processing in addition to the availability of very high-resolution images covering the same geographical area, it becomes possible to perform analysis in a fast and cost effect way. Such methods could be easily adapted for routine and serial analyses part of a wider monitoring program aimed integrated coastal management and long-term risk analysis.

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