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Evolution of the coast line and associated impacts in coastal Ceará State, Northeast, Brazil

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R E S U M O

Eventos de alta energia são cada vez mais frequentes no Nordeste do Brasil. Destes mencionamos ressaca entre dezembro e abril, causando vários impactos nas áreas costeiras. Portanto, o objetivo deste capítulo é estabelecer a evolução da linha costeira da cidade de Aquiraz no período de 1958 a 2014 e de 2009 a 2014, para identificar as tendências de erosão e assoreamento, os tensionadores naturais e antropogênicos associados a esses procedimentos. Na metodologia, a linha de inundação máxima foi escolhida como indicador de avanço ou recuo da linha de costa, identificada em imagens de satélite QuickBird e Landsat e fotografias aéreas. O programa DSAS foi aplicado à evolução do litoral nos últimos 56 anos. Verificou-se que a costa está em fase erosiva progressiva. Entre 1958 e 2014, o AEPR do Japão passou de -0,07 para -1,29 m / ano e o Porto das Dunas de -0,29 para -2,61 m / ano. A reflexão desta ação humana coincide com o período de maior recuo do litoral em toda a área. As dunas frontais estão dispostas de forma descontínua, estão ausentes em alguns lugares devido à ocupação de tendas e construções fixas. Assim, este estudo de linha costeira foi uma ferramenta essencial para aprofundar a dinâmica local, a fim de sugerir novas medidas de mitigação, gerando novos dados considerando o avanço da ocupação e as mudanças climáticas e oceanográficas.

Palavras-chave: erosão costeira; vulnerabilidade; Aquiraz.

A B S T R A C T

High-energy events are increasingly frequent in Northeast Brazil. Of these we mention undertow between December and April, causing several impacts on coastal areas. Therefore, the aim of this chapter is to establish the evolution of the Aquiraz city's coast line in the period 1958 to 2014 and from 2009 to 2014 to identify erosion and silting trends, the natural and anthropogenic tensioners associated with these procedures. In the methodology, the maximum flood line was chosen as an indicator of advance or retreat of shoreline, identified in QuickBird and Landsat satellite images and aerial photographs. The program DSAS was applied to evolution of the coastline in the last 56 years. It was found that the coast is in progressive erosive phase. Between 1958 - 2014, Japan's AEPR from -0.07 to -1.29 m / year and Porto das Dunas from -0.29 to -2.61 m / year. The reflection of this human action coincides with the period of greatest retreat of the coastline throughout the area. The frontal dunes are arranged discontinuously, are absent in some places due to the occupation of tents and fixed constructions. Thus this coastal line study was an essential tool to deepen regarding the local dynamics in order to suggest further mitigation measures by generating new data considering the occupation advancement and climate and oceanographic changes.

Keywords: coastal erosion; vulnerability; Aquiraz.

Introdução

Shoreline retreat rates are one of the best indices for coastal erosion monitoring, especially when it reaches advanced stages. In most cases, this ratio is more explicit and often more reliable than evaluation only of the eroded volume (Dias et al, 2005). The indentations of the shoreline are caused and exacerbated by lack of sediment, engineering works, sea level rise and high energy events (Smith et al, 2004; Rosati, 2005; Patschi & Giggis, 2006; Masselink et al, 2009; Bender et al, 2010; Bulhões et al. 2014; Maia et al. 2016).

The decreased amount of sediment is responsible for the shoreline retreat in various regions of the country and could be due to various human activities within the watershed, from setting the areas of sediment bypass within the coastal zone, dredging, coastal construction, to occupation (Masselink & Rughes, 1998; Leont'yev, 2003; Toldo Jr. et al, 2006; Dean & Dalrymple, 2004; Ciavola et al, 2007; Rughes & Nadal, 2009)). Seasonality of climatological and oceanographic processes, as observed in the Northeast of Brazil, is responsible for alternations between erosion and siltation cycles on the beaches. Adaptation to the scenario of sea level rise and the increasing frequency of high-energy events are a major challenge today for the territorial reorganization and management of urban coasts, considering the impacts on infrastructure and services associated with it (Calliari et al, 1998; Mitchell et al, 2009; Macedo et al, 2012; Boeno & Ferrão, 2016).

The following fetures are the most common used to determine the coastline and in monitoring it as erosion indicators: dune front base, vegetation line, base of the cliff, and the high water line in the spring high tide (Muehe, 1998). The choice of the best indicator will depend on the morphology most evident in a specific coastal area or that one which will be best seen in the images and photographs, and; or that feature which provides increased reliability from the results (Carvalho & Gherardi, 2005). The high tide line was chosen in this work because it is the clearest indicator between the dry part and wet part attributed to shades of sand, identified in the images and photographs, as well as being displayed in all time series.

In this context, the high tide line is an important indicator for understanding the processes between the frontal dune systems and the beach, as this is introduced as a major factor, especially when dealing with high-energy events.

Several coastal areas in Brazil are under alert whether from advanced processes of erosion or from more frequent flooding. In the Brazilian Northeast, specifically in the city of Recife, the Boa Viagem beach lost about 2.5 km of sandy strip since the 1990s (MAI, 2010). The diagnosis published by the Ministry of the Environment - MMA (2010) points out that half the coast of Paraíba (70 km) is threatened by erosion. The beach of Pau Amarelo, another one of the coast of Pernambuco, constituted of an area very urbanized and important for the tourism and the local economy, also undergoes intense processes of reduction of the praial band, consequence of the local hydrodynamic conditions and installation of breakwaters South (Martin & Pereira, 2014). On the coast of Ceará, in the next ten years, four beaches will disappear; they are Barreira (Icapuí) Caponga (Cascavel) Icaraí (Caucaia) and Morgado (Acaraú) (Morais et al., 2006). In Retiro Grande, a coastal beach in Icapuí, Ceará, the process of decreasing the stretch strip is associated with a lack of sediment input, because it is a rocky coast composed of cliffs (Souza et al, 2016). In the metropolitan área of Fortaleza the studies by Meireles (2008), Pinheiro (2000), Pinheiro *et al* (2001), Morais *et al* (2006), Oliveira *et al* (2005) Oliveira & Meireles (2008; 2010) stand out.

Storms were cited as the main causes of sea advancement and destruction of frontal dunes and beach strip in the system of Ria Formosa, in Portugal (Ceia et al (2010). On the beaches of Sydney, Australia, the retreat of the coastline is associated with storm events and the quantifications of their impacts have been used as variables in coastal planning (Callaghan et al (2009). On the southern coast of Rhode Island, US extreme storms make the coastline susceptible to erosion in sectors where the frontal dunes are further lowered or cut by wind runners (Shaw et al, 2016). According to Harley et al. (2017) extratropical cycles are responsible for the episodic erosion of large-scale beaches along the coasts of temperate regions. However, the main drivers of regional variability in the rapid morphological changes caused by extratropical cycles are poorly understood.

Faced with the above, it is apparent that natural phenomena and human driving forces take on a world scale, but are mainly observed in the regional and local scales, where the severity of these events is consonant with latitude, geology, oceanographic parameters, morphology, particle size, level of occupation and exploitation of the coastal zone.

In view of the above, the purpose of this chapter is to establish the evolution of the coast line of the city of Aquiraz in the period 1958 to 2014 and from 2009 to 2014 to identify trends in erosion and silting, the natural and anthropogenic forces associated with these procedures.

Area of Study

The city of Aquiraz is located in the northeast of the State of Ceara, occupies an area of 482.8 sq. Km and distance 24.70 Km (headquarters) of the city of Fortaleza. Is integrated on the east coast of Ceara totaling 30 miles of beaches. (Figure 1). The municipal Headquarters is located at the coordinates 3 ° 54 ' 05 "S (latitude) and 38 ° 23 ' 28 "W (longitude), at an altitude of 14.23m. The geomorphological bays of the study area are in the direction of the ocean-continent, the following: beach Strip (beachface), foredunes, plains of deflation wind and fixed dunes (Oliveira and Meireles, 2010). About the winter profile, the beach has an average slope of 5° tending to horizontality with angles stronger in berm. In this period, it is observed that the concentration of coarse sediment levels in upper and lower beachface. On the summer profile, it has a beach with average slope of 15), where the sediments are more homogeneous and the line of berm better defined. The material is presented with fine to medium sand at the top level of the beachface and medium to coarse at the bottom (CARVALHO et al, 1994).

The tidal cycle has as scheme the type semi-diurnal (two high and two low tides) and amplitude of type meso-mare (mesotidal) reaching on average 2.5 m can reach up to 3.2 m In the events of high energy between 2010 and 2013 the waves (sea) predominant presented average period of 7.5 s and a height of 0.8 m, and the dimples (swell) period of 12 s and height between 1.0 and 1.5 m in height. The predominant direction of incidence is respectively, ENE and E in the first half, ESE and SE in the second half of the year. Therefore, combined spring tide and waves totaling a maximum of 4.7 m, causing much sediment mobilization and local erosion.

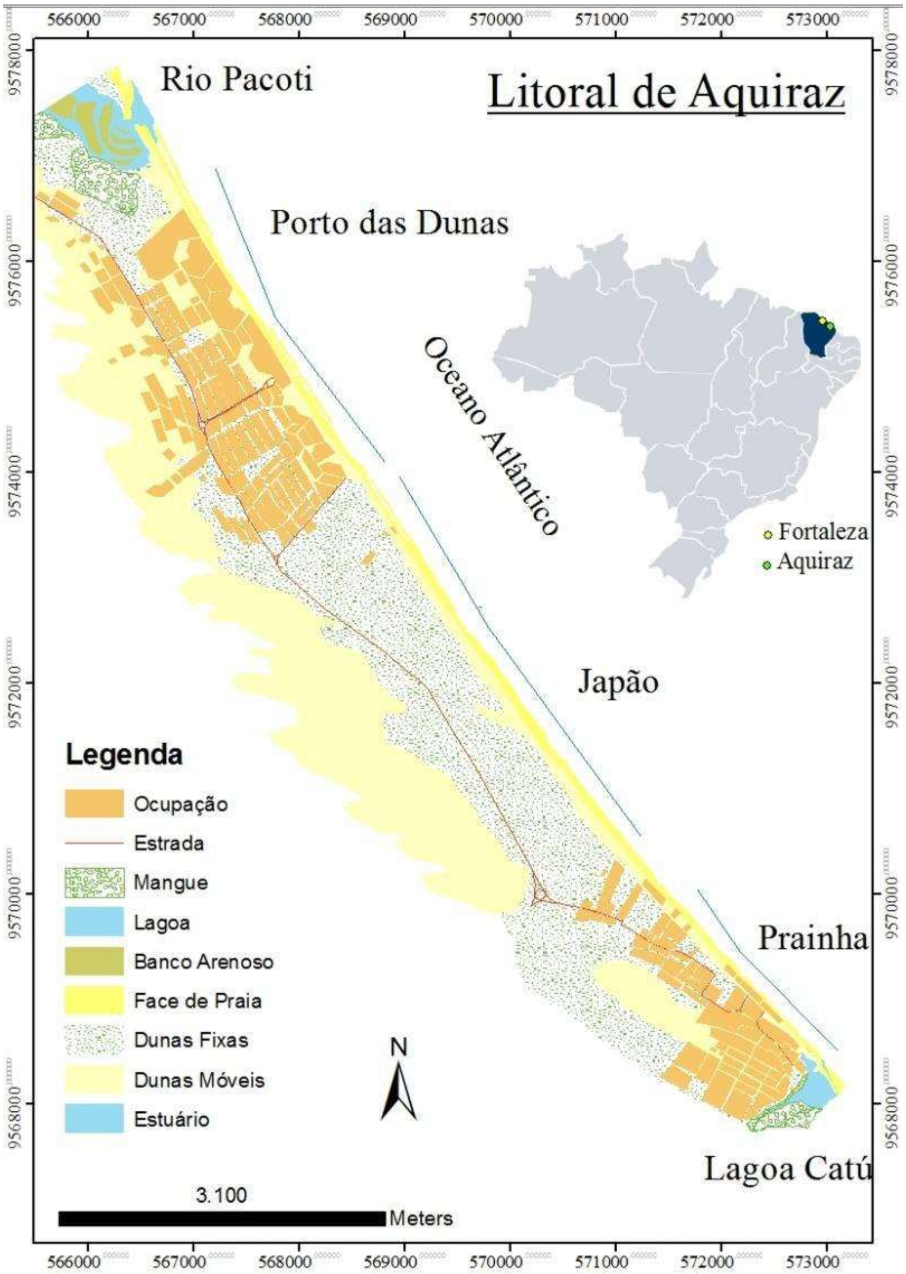


Figura 1. Location on the coast of Aquiraz, which extends over 36 km in the central region of the state of Ceara.

Methodology

In the study Quickbird images were used for the projection, Datum WGS 1984 - Zone 24S 2004, 2008 and 2009 provided by the State Superintendent of the Environment - SEMACE, 1988 and 1999 Landsat images, Datum WGS 1984 - Zone 24S provided by the National Institute for Space Research - INPE, Quickbird images 2013 and 2014 for the projection, Datum WGS 1984 - Zone 24S extracted from Google Earth, and aerial photographs at a scale of 1:70,000 dated 1975 provided by the National Institute of Colonization and Agrarian Reform - INCRA and 1958 by the Geological Survey of Brazil - CPRM.

A mosaic was generated from photographs in digital format. The georeferencing of the tracks was carried out in software ArcGis 9.3 from 04 control points, such as roads, which would be the only identifications present in both photographs and images. The 2014 image was chosen as datum for the calculation due to the low resolution of the picture of 1975 (the oldest) thus preventing significant errors. As for the 2011 line, it was obtained by traversal of every high tide line with the aid of the global position system - GPS not only recording the high tide line, but also areas of occupation and erosion. The estimated error in handheld GPS for traversal was in meters (Quintela, 2014).

Shoreline Evaluation Criteria

The high tide line was chosen as an indicator due to the clear view of the shades of sand between the dry part and wet part, identified in satellite images and photographs. Shoreline mobility rates were calculated for Japan beach and Porto das Dunas beach, in the municipality of Aquiraz. Beaches are classified according to the typologies of Moraes (2007) as: residential urban or densely populated tourist (Porto das Dunas) and isolated or semi-isolated (Japan).

Using the Digital Shoreline Analysis System - DSAS 4.2

In this step, the shorelines were vectorized in the format of shapefile, through temporal data in the tool Geographic Information System - GIS in order to quantify the variation of the shoreline and identify most of the critical points in the area. Quantitative analysis of the shoreline was obtained through extension of the Digital Shoreline Analysis System - 4.2 DSAS developed by Thieler et al (2005) for ArcGis® platform, provided free of charge, which functions in the Environmental Systems Research Institute (ESRI).

The DSAS works generating transect orthogonal to a baseline determined by the user (baseline) in a defined spacing, and then calculates the change rates through different statistical methods which are shown in a table of attributes. (Farias & Maia, 2009). To calculate the change rate of the coastline (polygonal beach) from aerial photographs and maps, the computational methods used were: (a) termination point or End Point Rate (EPR), through which is measured the horizontal distance between two positions on the long coast line, preferably over several stretches of beach and involving only two periods of time (this is the proxy method most widely used in the United States); (b) average of EPRs or Average of EPRs (AEPR), through which different EPRs are calculated for various periods, the final rate being the arithmetic mean of the set of values; (c) Weighted Linear regression (Linear Weighted Regression), statistical method in which the best measure is given by the sum of the squares of the differences (least squares) between the various positions of the shore line obtained in time and measurements on various stretches of the beach; (d) Average of least squares (Least Mean Squares) (Dolan et al. 1991 Huneycutt et al. 2001 Esteves et al. 2009).

To calculate the area of each sector, a simple linear regression rate- LRR was used which considers the existing inflections along each coast line (Farias & Maia (2010). Negative values represent the areas of erosion, whereas the positive values signify progradation area. Areas were obtained and the changes calculated in the five reporting periods: (1958 - 2014); (1988 - 2014); (2009 - 2014); (2013 - 2014). In each beach polygon control transects were then plotted perpendicular to the coast line and approximately equidistant from each other, following the methodology of Souza & Luna (2009). For verification and proof of retreat or advance of the coastline, the transects were distributed in such a way that they cover the beach monitoring points.

Calculation of Yearly width of the beaches and mobility rates

The methods End Point Rate (EPR) and Average of EPR's (AEPR) were used to calculate the annual width of the beaches in each transect, obtained by the arithmetic mean. Following the same methodology, the EPR is the difference between the values of width of each transect for the reference period and the AEPR is the arithmetic mean of each EPR calculated for the set of every year. The average totals were variations calculated of width for each beach as well as well as the total average of AEPR's. The methodology used and geoprocessing techniques allow the calculation of the average rate of retrogradation or progradation in the ratio between the average of the AEPR's and the time interval considered (56 years).

Results and Discussion

Japan Beach

On Japan beach the highlight is the extensive frontal-type dune field and for not having any relevant occupation. Five points were marked for tracking: Point 04 - Spell Tent; Point 05 - Ruins; Point 06 - Fisherman's Tent; Point 07 - Tadeu's tent; Point 08 - Road. The profiles range from a fixed point on the road through the dunes until you reach the shore front, extending 250m - 230m - 210m - 172m - 151m respectively.

The waves in that stretch reach the average height of 0.90 cm and the swash extends from the low-water line between 48m to the mainland at Point 08 and 130 m at point 07. As for the change rate of the shoreline, 30 transects were generated perpendicular to the base line and spaced at a distance of 150 m, around 4500 m (Figure 2).

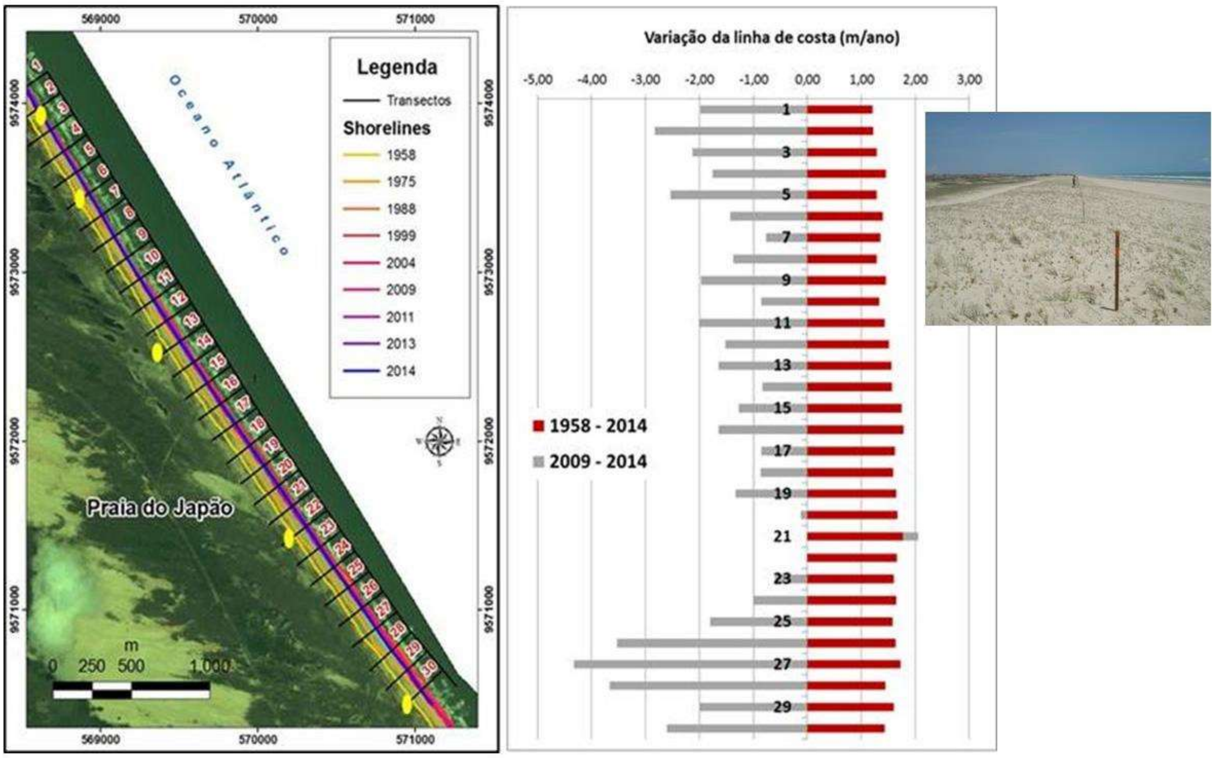


Figura 2. Evolution of the Coast Line of Japan's beach obtained through the Medium of EPRs for 1958 Period 1975 1988 1999 2004 2009 2011, 2013 and 2014 with 30 transects . The circle in yellow indicate the Five Points monitored.

For the period 1958-2014 the beach at all transects was in progradation ranging from 1.21m / year (T1) and 178 cm / year (T16); occurring also in the period 1975-2014, ranging from 0.50 m / year (T30) and 1.61m / year (T22). In the period 1988-2014 retrogradation processes occurred for almost all transects, only a few had positive values which did not reach 0.50 m / year of progradation. In this case, the variation was from 0.46 m / year (T12) to -1.71m / year (T28), then in the period 1999 to 2014 the decrease was more significant, ranging from 0.19m / year (T3), only this positive value, and -2.96m / year (T30). There was progradation in most transects with small negative changes in the 2004-2014 period, with 1.82m / year (T24) and -0.26m / year (T2).

In the period 2009-2014 the retrogradation settled in and much stronger, ranging from -0.29m / year (T21) and -4.33m / year (T27). Back to prograde in most transects, with negative values in the last transect (near Prainha) in the 2011-2014 period, with values ranging from 2.88m / year (T20) and -2.20m / year (T27). And finally, in years 2013-2014, erosion has very significant values compared to the other periods, varying between -0.24m / year (T17) and -11.09m / year (T13) (Figure 01)

Observing the values for each period, the first two were stable prograde environments because there was no place with erosion. In the 1980s most transects were negative or positive values of little significance. But the location of these negative values tends to be at the extreme limits of the beach, that is, where there is some kind of occupation (end of Prainha and beginning of Porto das Dunas). (see figure). It was in the 1990s that erosion was installed throughout the section, the transect near Prainha beach being highlighted (T19 to T30). And from there on, the erosion levels only increased at both ends of the beach.

In periods of 2004 and 2011 the rates were positive in virtually all transects of the beach, unlike what was observed in 2009. In 2013, high erosion rates are found among the transects (T1) and (T13), near to the beach of Porto das Dunas.

The years of monitoring (2010 - 2012) in conjunction with older data of the area, show that the sector receives great energy from waves associated with tidal syzygy, materialized on the slopes formed during high tide where the beach strip is completely covered .

Currently (2013-2014), the impact on this sector is much higher because of the landscaping of dunes and sand removal for construction of condominiums and resorts. It is affecting the frontal dunes and beach strip. The result of this, is the negative values found in this period, reinforcing the erosion that was already present, even when there was no occupation or more overt interventions.

The total averages of each EPR (AEPR) are as follows: in the period 1958-2014 the average was 1.52m, 1.17m for the period 1975-2014. With -0.22m erosive processes in the period of 1988-2014, -1.32m in the 1999-2014 period, in addition to 0.55m in 2004-2014, -1.63m in the period 2009-2014, to be added back in the period of 2011-2014 with 0.87m and heavy erosion in the period 2013-2014 with the average - 4.29m.

Japan beach's has natural and dynamic characteristics that stand out, in that a beach with low capacity is considered, but the erosive and reverse processes are more evident. In a more recent study by Moura et al (2016), the retreat of the coastline in Prainha, a locality about 1 km from the beach of Japan, is justified not only by the possible changes in sea level rise, but due to the decrease in the sedimentary supply caused by the occupation of housing and summer equipment in bypass and dune fields.

Porto das Dunas Beach

It is the most urbanized sector of Aquiraz. Fully geared for tourism and summer resort in which its facilities and structures are on mobile dunes and a beach strip with strong interference in the coastal dynamics. There are two monitored points: Point 09 - Oceani Resort and Point 10 - Beach Park. They have approximate distances of 1km and beach tracks reaching 159 m in this direction. The waves in this sector ranged between 0.89 and 0.91cm and at low tide cover on average a 370 m length of beach and dune front profile.

30 transects were generated at distances of 100 m, totaling 2,950 m. So also other resorts, Hostels and hotels were reached that are installed in this passage georeferenced through the bimonthly traversal using GPSmap 62s - GARMIN and then plotted in MapSource software (Figure 3).

The EPRs for shoreline were of accretion between the periods 1954-2014 and 1975-2014, which varied: 1.12m / year (T26) and 0.46 m / year (T7) in the period from 1958 to 2014 and 1.82m / year (T6) and 0.35m / year (T29) in the 1975-2009 period. In the period 1988-2014, it was largely erosion, except for transects (T25, T26 and T28) with positive values (0.15 and 0.16 respectively), but lower than in previous periods. In this time period the figures varied from 0.16m / year (T28) and -1.41m / year (T2). From the period 1999-2014, the figures were all negative. In this case, the figures ranged from -0.71 m / year (T23) and -3.66m / year (T2); between 2004-2014 the change was -0.33m / year (T3) and -1.58m / year (T18): between 2009-2014 it was -0.20m / year (T26) and -4.45m / year (T30),), corroborating with the results presented by Marino and Freire (2013); in the period 2011-2014 the line varied from 1.67m / year (T25) and -3.98m / year (T13) and, finally, in the period 2013-2014, the variation was from -1.47m / year (T21) to -13.89 m / year (T18) (Figure 3).

Unlike previous beaches, the period of 2011- 2014 was always in accretion, this had not occurred on the beach of Porto das Dunas. This beach has also presented more significant erosion at its limits than in the central portion. Among the T13 and T21 transects, is located the renowned resort and aquatic club Beach Park. Built in 1985 and since then, the park has only grown, and along with it, dozens of other resorts. They were built more recently forming a mega tourist complex of dunes and beach strip. However, only in 2013 we could see more severe erosion, which arouses curiosity as to how so many interventions had not previously affected this stretch. The anthropic interference is so striking in the case of this beach, bringing damage to the coastal environment and the entire ecosystem involved.

The sector in the first two periods was balanced in the sediment dynamics, deposition and evolution of the coastline. However, from the third period the area has undergone erosion in transects near Japan beach and very significantly also between 2009 and 2013 in the next transect at the mouth of the Pacoti.

The critical period started from 1999 (a decade after construction of Beach Park) where all transects show erosion, which subsequently has a progressive disposal over the period, but by 2009, with a reduction of the negative values (Figure 3; Figure 4). From 2011 to 2014 has seen a jump in values that represent erosion at this beach.

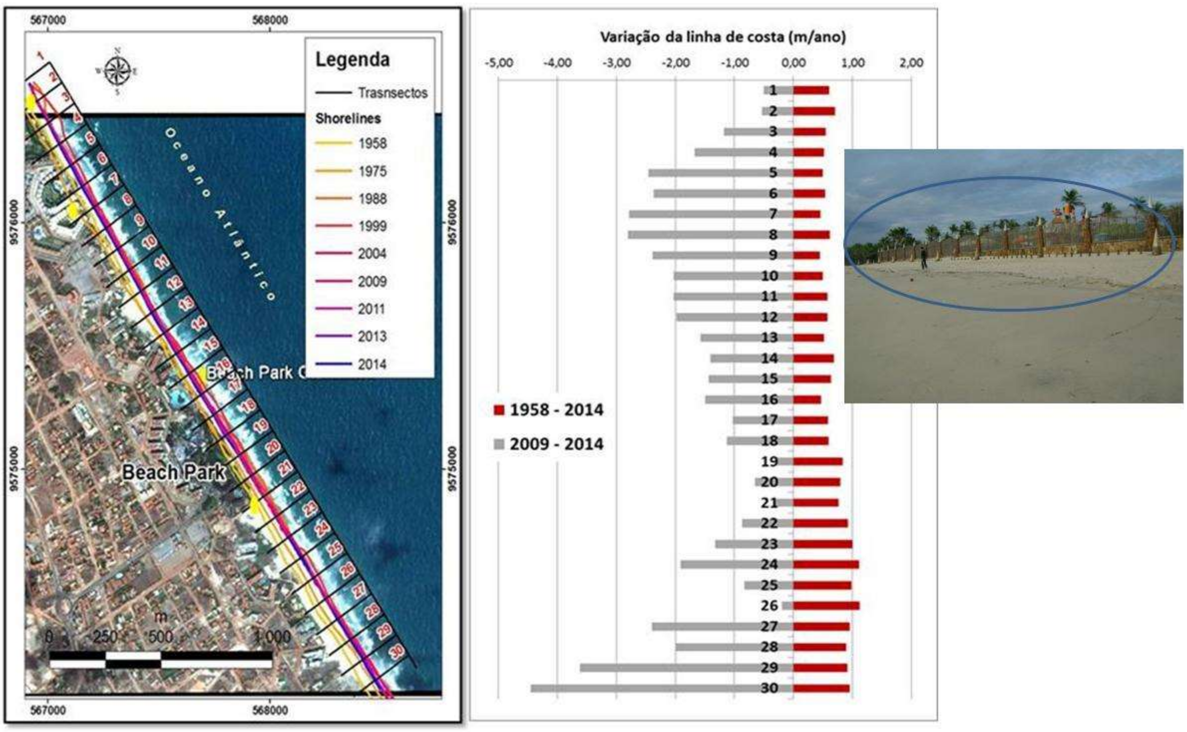


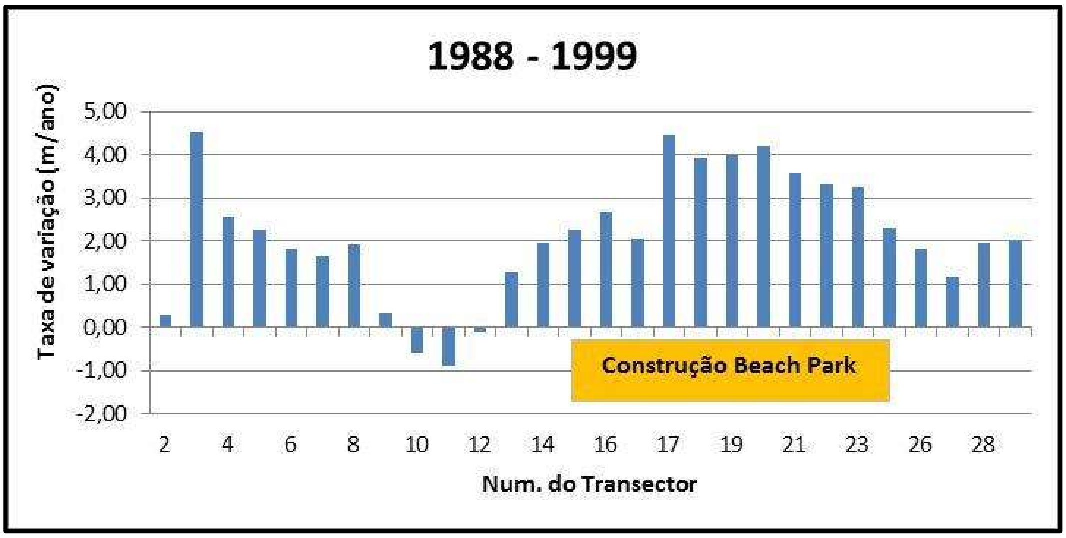
Figura 3. Evolution of the coast from the beach of Porto das Dunas line obtained through the medium of EPRs for the period 1958 1975 1988 1999 2004 2009 2011, 2013 and 2014 with 30 transects . The circle in yellow indicate the three monitored points

The most affected area is located in transects where Beach Park and neighboring resorts operate (T11 to T21), for which, for their expansion and construction, it was necessary to remove the field of mobile dunes and silting interdune ponds. This brings a Sedimentary deficit associated with high energy events like undertow, causing wide displacement of these sands (offshore), and sometimes it does not return to the beach strip, ending in an irreversible framework for its dynamic balance.

The data of total average (AEPRs) also says that erosion occurred in the area with a dynamic relationship and its impact: 0.72m (1958-2014); 0.94m (1975-2014); -0.45m (1988-2014); -1.57m (1999-2014); -0.80 M (2004-2014); -1.69 M (2009-2014); -1.62m (2011-2013) and -6.30m (2013-2014)

As the beach is the last (western sector) the sediment demand should be the most affected, because dunes and post - beach no longer exist to feed them, there remains a considerable stretch of beach, for this occasion, and earlier beaches that are also in erosive and retrogradation processes. Thus, stability is critical and biased toward future losses of urban structures and the entire resort complex due to the advance of the sea. Marino and Freire (2013) point out that the near impact of the urban environment, as a result of occupation and exponential urban growth, mainly in the Porto das Dunas and Praia do Futuro region, Fortaleza, Ceará, implies a decrease in the sedimentary contribution that serves as food for the maintenance of the coastal zone, especially the strip of beach.

The construction of vacation homes and resorts is frequent and growing to the extent that the population of Fortaleza moves to these beaches not only for leisure, but, lately, for housing, resulting in the last 40 years in evidences of erosion and economic and environmental damage with the advance of the sea (Oliveira (2009).



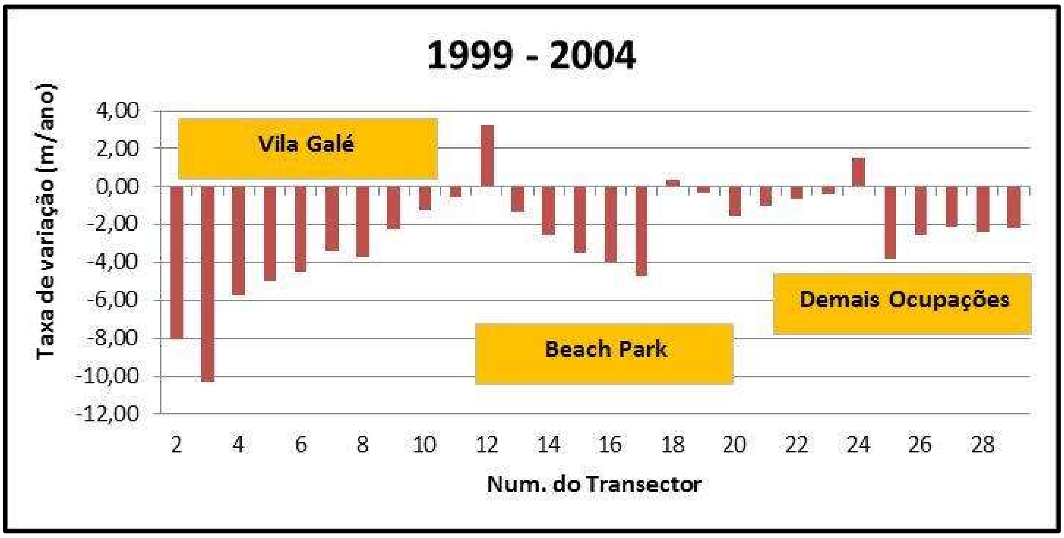


Figura 4. Growth rate in m / year periods 1988-1999 and 1999-2004 on the beach Porto das Dunas.

Figure 04 - occupation sectors in all the studied in Singapore and the variation of the coastline.

Conclusões

The east coast of Aquiraz is in a progressive phase of erosion since the 1950s. This stage markes significant changes occupation of the beach areas, consolidated by summer houses and later in the 1980s made it possible to build a "coastal-maritime city" (Dantas, 2002) from the building of resorts, Hotels and gated communities and luxury beach huts.

The reflection of this human action coincides with the period of greatest retreat of the coastline throughout the area. The beaches of Porto das Dunas and Prainha, considered urbanized areas, have coastline erosion, however, with similar or lower level compared to previous levels, with risks of flooding during high tide due to waves reaching close to structures.

The frontal dunes, arranged discontinuously, are absent in some places due to the occupation of tents and fixed constructions.

The coastline study of the past 56 years was an essential tool to deepen understanding regarding the local dynamics that are associated with other data such as oceanographic parameters (wave and tidal) and sedimentological data on the dunes and beach strip field. They contributed to identify which variables are acting in retreat and erosion, to suggest further mitigation measures by generating new data taking into account the advancement of occupation and climatic and oceanographic changes.

Stretches susceptible to erosion are found on the east coast of the municipality of Aquiraz, in the Fortaleza metropolitan area in urbanized beaches such as Porto das Dunas and Prainha. In natural beaches such as Japan, these features are still preserved. Despite the disparate realities, both in periods of high energy associated with spring tides, there are steep fronts and waves beyond the berm crest reaching the frontal dune.

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