World Academy of Science, Engineering and Technology
International Journal of Environmental and Ecological Engineering
Vol:8, No:3, 2014

Comparison of Prognostic Models in Different Scenarios of Shoreline Position on Ponta Negra Beach in Northeastern Brazil

Débora V. Busman, Venerando E. Amaro, Mattheus da C. Prudêncio

***Abstract*—**Prognostic studies of the shoreline are of utmost importance for Ponta Negra Beach, located in Natal, Northeastern Brazil, where the infrastructure recently built along the shoreline is severely affected by flooding and erosion. This study compares shoreline predictions using three linear regression methods (LMS, LRR and WLR) and tries to discern the best method for different shoreline position scenarios. The methods have shown erosion on the beach in each of the scenarios tested, even in less intense dynamic conditions. The WLA_A with confidence interval of 95% was the well-adjusted model and calculated a retreat of -1.25 m/yr to -2.0 m/yr in hot spot areas. The change of the shoreline on Ponta Negra Beach can be measured as a negative exponential curve. Analysis of these methods has shown a correlation with the morphodynamic stage of the beach.

***Keywords*—**Coastal Erosion, Prognostic Model, DSAS.

I. Introduction

The privileged location of Natal (the capital of the state of Rio Grande do Norte in Northeastern Brazil) and the beautiful scenery of its white-sand beaches have promoted a rapid and unplanned recent growth in population and tourism. The population density increased from 2,490 people/km^2 in the 1980s to 4,800 people/km^2 in the year 2010. Along with this increase, there has been rampant erosion that has been becoming more intense since the beginning of 2010. This phenomenon has led to significant environmental and economic losses [7], [8], [14].

As in many coastal cities in the world, Ponta Negra Beach has become extremely urbanized and a promenade and boardwalk were built along its shoreline. Development in coastal regions continues growing despite the fact that coastal construction is subject to flooding and erosion [5]. Erosion is one of the main risk factors and causes coastal vulnerability for many beaches in the region, including that of Ponta Negra.

The city of Natal is one of the sites for the 2014 World Cup, domestic and international tourists flock to it year round and it is responsible for a significant part of the local Gross Domestic Product (GDP). Therefore, diagnostic studies as well as coastline projection studies are very important to help planning and integrated coastal management and to aid in decision-making for local government and business-owners.

To decide which the regressions methods is the best for the situation of the shoreline position on Ponta Negra Beach (Fig. 1), this study aimed to carry out and compare shoreline predictions using three linear regression models: Linear Regression Rate (LRR), Least Median Squares (LMS) and Weighted Linear Regression (WLR), available in the Digital Shoreline Analysis System (DSAS) [10]. Reference [2] shows the comparison between methods of shoreline erosion rates in Maui, Hawaii and [12] compared shoreline data from multiple sources such as remote sensors and terrestrial system collections (Global Positioning System and Light Detection and Ranging) in South Carolina (EUA). Even though predictions have already been made for other beaches in the Rio Grande do Norte State [6], this is the first comparative study of its type to be done on Ponta Negra Beach.

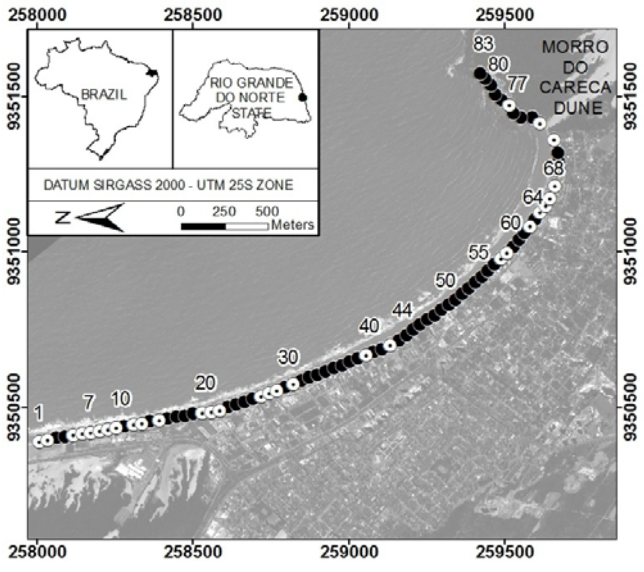

Fig. 1 Map of the location of the study area and transects (black and white dots) position. The white dots represent also the erosion hot spots

II. Methodology

Shorelines changes were extracted from moderate resolution Landsat 5-Thematic Mapper (TM) satellite images. These images were geometrically corrected from

D. V. Busman is with the Federal University of Rio Grande do Norte, Center for Science, Department of Geology. Campus Lagoa Nova, Lagoa Nova, 59078-970. Natal, RN, Brazil (e-mail: busman_dv@hotmail.com).

V. E. Amaro is with Federal University of Rio Grande do Norte, Center for Science, Department of Geology. Campus Lagoa Nova, Lagoa Nova, 59078-970. Natal, RN, Brazil. (phone: +55-84-3215-3212; e-mail: amaro@geologia.ufrn.br).

M. da C. Prudêncio is with Federal University of Rio Grande do Norte, Center for Science, Department of Geology. Campus Lagoa Nova, Lagoa Nova, 59078-970. Natal, RN, Brazil.

orthorectified images by the United States Geological Survey (USGS), and Root Mean Square (RMS) errors higher than 1 were not accepted. Baselines were established parallel to the shoreline and perpendicular transects 50m apart were made from them along the entire beach.

It was calculated the shoreline data to measure its change using the DSAS calculations developed by the USGS, which extended the functionality of its ArcGIS software. The analysis methods used to determine shoreline regression were Linear Regression Rate (LRR), Least Median Squares (LMS) and Weighted Linear Regression (WLR), and in this last were used different weighted to shoreline of years 1986, 1994, 2004 and 2012, and are called WLR_A, WLR_B e WLR_C. In the LRR method, a linear regression rate-of-change statistic can be determined by fitting a least-squares regression line to all shoreline points for a particular transect. Although the process of fitting the line to the data points follows the same logic as the LRR method, the LMS method is a more robust regression estimator that minimizes the influence of an anomalous outlier on the overall regression equation [10]. The weighted (w) is defined for (1) as a function of the variance in the uncertainty of the measurement (σ) [2]:

$$w = 1/(\sigma^2) \quad (1)$$

where σ = standard deviation.

WLR_A is the most weighted (1.0, 1.5, 2.25, and 3.375) and takes the form of an exponential curve. WLR_B also has the form of an exponential curve but is less weighted (1.0, 1.25, 1.5 and 2.0) while WLR_C shows a straight line and is weighted at an intermediate level (1.0, 1.5. 2.0 and 2.5) (Fig. 2). The highest weighting has been given to the most recent shoreline results seeing that it represents its current situation and also provides the most reliable data.

The importance of the different weighting was analyzed by subtracting the results from the determination coefficients (R^2) for the prognostics models and by analysis of 'hot spots' erosion along the beach. After this, graphs were prepared to facilitate discussion, analysis and conclusions. The statistical analysis was carried out by Program R [13].

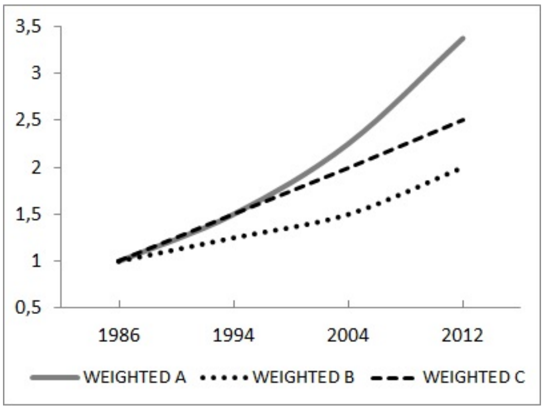

Fig. 2 Weighted curve of models WLR_A, WLR_B and WLR_C

III. Results and Discussion

All of the regression methods showed similar results and indicated that more than 97% of the beach is subject to erosion in each of the observed scenarios; however, they differed slightly in terms of the intensity of the erosion (Fig. 3). The shoreline prediction curves were comparable and showed overlap on certain points along the beach. The major differences in the curves occurred between transect 7 and 44 (1.8km) and the smallest differences in the curves, between transects 1 and 7 (0.35km) and 44 and 83 (1.95km), next to the Morro do Careca dune. The greatest adjustment was observed in the determination coefficient (R^2) when it reached 1.0 and in the amplitude of the confidence intervals, which were lower in these areas.

The predictions were only positive at three points and at one point indicated a stable shoreline (at transects 54, 55, 77, and 80). Despite the fact that the accretion rate ranged from +0.06 m/yr to +0.21 m/yr these predictions are not reliable considering that their determination coefficients are very low, between 0 and 0.16 (Fig. 3 (a)). Almost 30% of the determination coefficients in all of the predictions were above 0.7 and about 23% of them were between 0.5 and 0.7 thus proving that the models were well adjusted.

The most different prognostic curve was the LMS method and the highest differences were from transects 68 to 83, like occurred in the other methods (Fig. 3 (b)). The amplitude ranged from -1.89 to +0.09 m/yr, with a mean and median about of -0.6 m/yr, and a mode of -0.5 m/yr.

The LRR model of the rate of shoreline variation for the projected regression was the least of all the models and ranged from -1.82 m/yr to +0.06 m/yr with an amplitude of 1.88 m/yr, a mean and median of -0.7 m/yr, and a mode of -0.76 m/yr (Fig. 4 (a)). The determination coefficient of the LRR method showed a high correlation: 25% of the coefficients were between 0.5 and 0.7 and more than 30% were more than or equal to 0.7. The amplitude of scenario that the WLR_A estimated projection was 2.21 m/yr and ranged from -2.0 m/yr to +0.21 m/yr. The mean and median values show a retreat of approximately -0.9 m/yr and the most frequently calculated retreat was -1.3 m/yr. This method had the highest determination coefficients: approximately 60% of them were equal to or more than 0.5 and 29% were above 0.7. The variations calculated using the WLR_B method showed results from -1.91 m/yr to +0.12 m/yr with a mode of -0.7 m/yr and approximately 53% of the coefficients were equal to or greater than 0.5. The WLR_C method calculated a -0.88 m/yr modal variation and had a maximum retreat and advance of -1.97 m/yr and +0.17 m/yr respectively. It was a well-adjusted projection in over 50% of its data. Summarizing, all of the predictions presented well-adjusted and reliable data and exhibited a shoreline retreat in each scenario, both in the modest and intense models.

For the weighed regression, data that had a lower of uncertainty of shoreline position has been given more importance in order to determine a better-adjusted line [10], for example, given more weighting on the more recent data. The WLR_A model was the strongest model where the most recent data was given more weighting and described an exponential function. The WLR_B model was the least strong of the three and presented a more gradual exponential function. The WLR_C model was seen as an intermediary model and showed a straight line. When analyzing the determination coefficients, the WLR_A model showed the highest quality of adjustment for the projections on the majority of the beach (Figs. 4 (a), (b), 5). The most frequent determination coefficient was 0.81 and the median was 0.49.

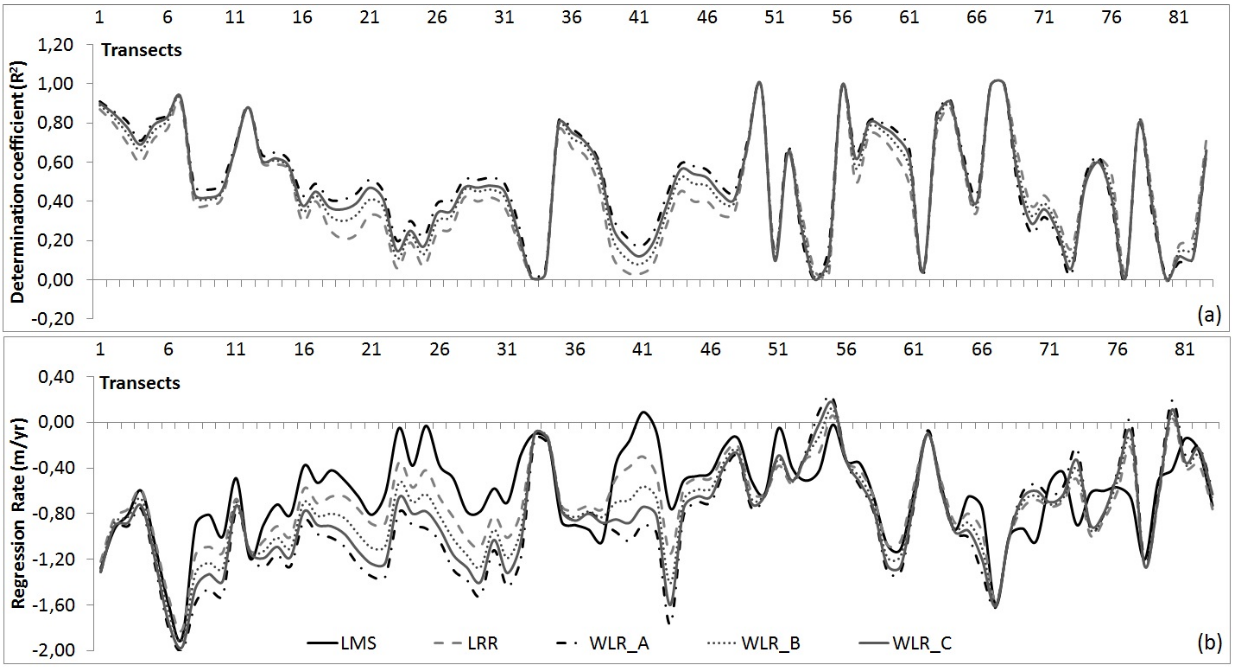

Fig. 3 Determination coefficient curves (a) and shoreline projections for Ponta Negra Beach (b)

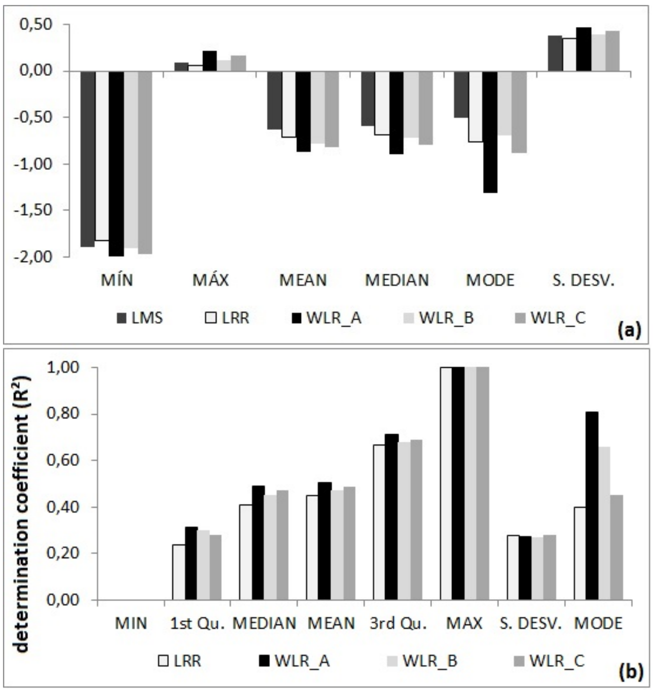

Fig. 4 (a) Statistical data from the linear regression models with and without weighting and (b) from the coefficients in linear determination (R^2)

Reference [8] shows an analysis of multitemporal shoreline changes on Ponta Negra Beach from the 1986 to 2012 and have shown that the coastal processes have changed from accretion and a stable state in the 1980s to medium to strong erosion on the majority of the beach in the last decade. The WLR_A model was the best-adjusted model because it concentrated more weighting on the intensely erosive processes that took place most recently, that's why calculated a tendency line more downward (Figs. 3 (a) and (b)) and corresponded to the highest R^2.

The statistic data from the WLR_B and WLR_C models did not show significant variation. Even so, the results from the WLR_B model were more adjusted and had higher R^2 than the WLR_C model (Fig. 4 (b)). According to the principle of parsimony, between two models or ideas that have similar results, we must choose the one that fulfills less parameter, or in this case, the model with less weighted. Therefore, was defined that after model WLR_A, the best-adjusted model was WLR_B, which also showed an exponential function. These results confirm that the shoreline behaves as an exponential function more so than a straight line, that is to say that in recent years, erosion has intensified as [8] have shown.

The importance of predictions has analyzed by subtracting the determination coefficients (Fig. 5). The WLR_A projection had the highest until transect 68 (3.4km) where WLR_B and WLR_C proved more accurate with WLR_B having higher than WLR_C. All of the coefficients showed an inversion from this transect onwards but the WLR_B and the

LRR models were the most significant only in this region. Interestingly, Ponta Negra Beach shows dissipative characteristics from transect 1 to 55 and begins to transition into an intermediate morphodynamic state after transect 64 [3]. From transect 55 to 68 (0.65km) the projections showed little variation and overlapped at some points (Fig. 3 (b)). This stretch of the beach makes up the transition between a dissipative morphodynamic state and an intermediate morphodynamic state. By analyzing the determination coefficients we were not only able to identify the most accurate model but also the stretch of the beach where the each prognostic model was more important and its correlation with the morphodynamic state of the beach.

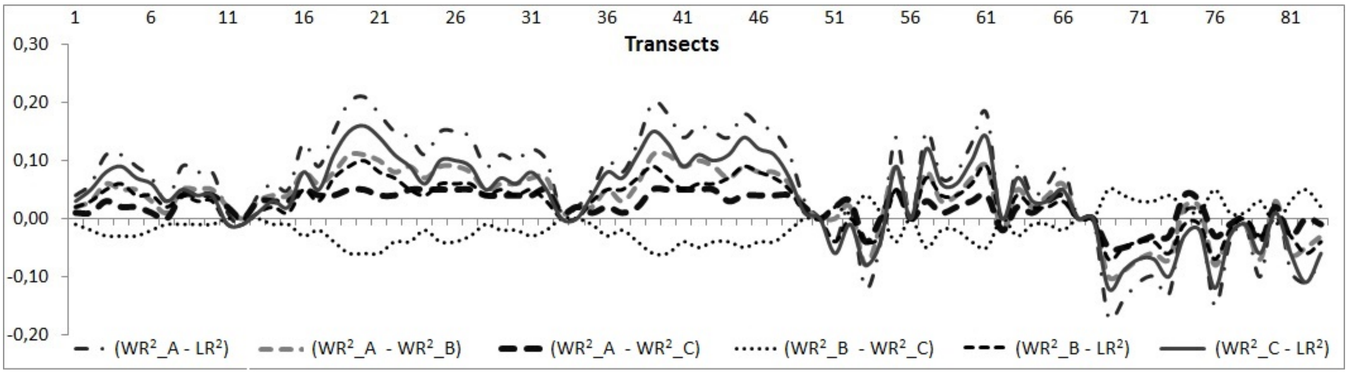

Fig. 5 Difference in determination coefficients (R^2)

The amplitude of the 68% confidence interval (CI68) ranged from 1.7m to 1.9m and was greater when the weighting was greater. This phenomenon occurred in the same way for the other confidence intervals. In the 95% confidence interval (CI95) the amplitude ranged from 5.8m to 6.5m and in the 99% confidence interval (CI99) it was between 23.4m and 26.0m. There was an approximate difference of 10% in the amplitudes of each confidence interval between the most discrete model, the LRR, and the most robust, the WLR_A. This fact confirmed WLR_A as the best predictor of the shoreline variation on Ponta Negra Beach since the well-adjusted values and the high amplitude of the confidence intervals in WLR_A were not drastically greater than the less-adjusted models. The confidence interval more adjusted and thrift was the CI95, because at CI68 only 68% of the prognosis is effectively in this band and the amplitude of confidence interval CI99 was almost 4 times greater than the CI95 interval. That is why the CI99 increase to 99% the chances of prognosis to be in these boundaries. Therefore, the model WLR_A with the 95% confidence interval was the most accurate model.

The confidence interval amplitudes were very high due to the small amount of data available. The DSAS was developed to measure the variation on the shoreline using a temporal series of data over time [9] and when more temporal data is available, the analysis is more reliable and accurate. While the USA and other countries often have a large collection of data over time, as described by [2], [4], [5], [11] and [12], Ponta Negra Beach only had four shoreline measurements over three decades [8] and [14]. This proved to be our biggest challenge in the study.

Nevertheless, this study has discovered important results about a shoreline subject to rapid retreat and the shoreline predictions are an important resource for coastal planning and management. Since the beginning of 2010 intense erosion has begun and given rise to harmful environmental and socioeconomic conditions along the waterfront on Ponta Negra Beach, such as destroying the boardwalk and the coastal infrastructure like kiosks and public utility networks (electricity, water and sewage) and increasing coastal risks, as noticed in [1], [7], [8] and [14]. It is very important to carry out shoreline projections of this type even though certain restrictions exist because time is of the essence when it comes to environmental issues. Therefore, the predictions made in this study will to refine and analyze in the future.

About 25% of the most intense erosion has been identified in Fig. 1 as “erosion hot spots” and can be used to support coastal management. These “hot spots” have been found along the whole beach but are the most concentrated in the first 1.55 km and the last 1.2km, areas found in a dissipative and an intermediate morphodynamic state, respectfully. These projections have shown that even in less dynamic conditions, such as in the intermediate stage, Ponta Negra Beach will retreat at least -0.9m/yr and at most -2.0m/yr. The WLR_A predicted a retreat of -1.25m/yr to -2.0m/yr in the hot spots, which is a significant rate for an urban beach.

The erosion and accretion cycle and their consequent destructive and constructive effects have occurred on this beach for many years; however, the most recent erosive cycle that began in February 2012 has been much greater than the previous ones and was responsible for unprecedented coastal destruction. These results have indicated that this cycle is more aptly represented with an exponential curve rather than a straight line as shown in the weighted model WLR_A. Considering that these phenomena rarely occur in a linear pattern, the weighted exponential model represents the prediction of erosion on the Ponta Negra shoreline more accurately. This hypothesis must be analyzed in future studies about coastline predictions, in order to make any necessary adjustments to the models.

IV. Conclusion

The prognostics exhibited well-adjusted and reliable data and detected a shoreline retreat in each of the scenarios tested. It was considered important to use different regression models and with different weightings to compare the shoreline positions. The models presented results ranging from inconspicuous to quite alarming and the WLR_A model in a 95% confidence interval was the best-adjusted regression model for Ponta Negra Beach.

The shoreline on the beach seems to follow a negative exponential curve more so than a straight line, which suggests that erosion has been more intense in recent years. If this trend is confirmed it may lead to even greater environmental and socioeconomic damage to the Ponta Negra Beach neighborhoods.

The projections indicated that even in less intense dynamic conditions such as the section of the beach in an intermediate morphodynamic state, Ponta Negra Beach will still experience a -0.9 m/yr to a -2.0 m/yr retreat, seeing that WLR_A predicted a retreat of -1.25 m/yr to -2.0 m/yr in the hot spots zone, which is a significant rate for an urban beach. The scenarios that showed the shorelines advancing were not validated by the statistic adjustment indicator (determination coefficient R^2) thus seem to suggest will not have possible construction along the shoreline in the next few years.

An analysis of the determination coefficients indicated the most significant method and in which beach sector each method was more important and correlated with its morphodynamic state.

This study can be used to support local governments, business owners and entrepreneurs to make informed decisions when facing problems related to the current and future scenarios of erosion. Even with reservation, this shoreline analysis with DSAS has proven to be a useful resource for coastal management. However, it is necessary to refine and validate these results with more local multitemporal data collection to increase the potentials of these prognostics.

Acknowledgment

The authors thank the Coordination for the Improvement of Higher Level or Education Personnel (CAPES) for the doctoral scholarship of the first author and the Brazilian Study and Projects Financial Agency (FINEP) that has provided support for the implementation of the research.

References

[1] A. L. S. Santos, V. E. Amaro, D. V. Busman, A. T. Ferreira, M. F. A. Matos, and M. S. T. Santos. “Erosion Aspects in Ponta Negra Beach, Northeast Brazil, through Remote Sensing and High Precision Geodesic Techniques,” in *12th International Coastal Symposium*, Plymouth, England. Book of Abstracts, 2013, pp. 235.

[2] A. S. Genz, C. H. Flercher, R. A. Dunn, L. N. Frazer, and J. J. Rooney. “The Predictive Accuracy of Shoreline Change Rate Methods and Alongshore Beach Variation on Maui, Hawaii,” *Journal of Coastal Research*, v. 23, no. 1, 2007, pp. 87–105.

[3] A.T. S. Ferreira, V. E. Amaro, and M. S. T. Santos. “Geodésia aplicada à integração de dados topográficos e batimétricos na caracterização de superfícies de praia” (Periodical style—Accepted for publication). *Revista Brasileira de Cartografia*, to be published.

[4] B. M. Romine, C. H. Fletcher, L. N. Frazer, A. S. Genz, M. M. Barbee, and S. C. Lim. “Historical Shoreline Change, Southeast Oahu, Hawaii: Applying Polynimoial Models to Calculate Shoreline Change Rates,” *Journal of Coastal Research*, vol. 25, no. 6, 2009, pp. 1236–1253.

[5] B. M. Romine, C. H. Fletcher, A. S. Genz, M. B. Barbee, M. Dyer, T. R. Anderson, S. C. Lim, S. Vitousek, C. Bochicchio, and B. M. Richmond. 2011. “National Assessment of Shoreline Change: A GIS Compilation of Vector Shorelines and Associated Shoreline Change Data for the Sandy Shorelines of Kauai, Oahu, and Maui, Hawaii,” *U.S. Geological Survey Open-File Report 2011–1009*.

[6] C. G. de M. Franco, V. E. Amaro, and M. V. da S. Souto. “Prognóstico da erosão costeira no litoral setentrional do Rio Grande do Norte para os anos de 2020, 2030 e 2040,” *Revista de Geologia*, vol. 25, 2012, pp. 37–54.

[7] D. V. Busman, V. E. Amaro, M. R. Câmara, S. N. Valcácio, and J. R. Sousa. “Coastal Protection on Tropical Mesotidal Beach: Case Study of Ponta Negra Beach, Natal/RN, Northeast Brazil,” in *12th Inter.l Coastal Symp.*, Plymouth, England. Book of Abstracts, 2013 a, pp. 38.

[8] D. V. Busman, V. E. Amaro, M. C. Prudêncio, F. G. F. Lima, M. F. A. Matos, and J. E. Moura. “Shoreline Changes from 1986 to 2010 on Ponta Negra beach, Natal / RN, Northeast Brazil,” in *SCACR International Short Course/Conference on Applied Coastal Research*, Lisboa, Portugal. Book of Abstracts, 2013 b.

[9] E. R. Thieler, and W. W. Danforth. “Historical Shoreline Mapping (II): Application of the Digital Shoreline Mapping and Analysis Systems (DSMS/DSAS) to Shoreline Change Mapping in Puerto Rico,” *Journal of Coastal Research*, vol. 10, no. 3, 1994, pp. 600–620.

[10] E. R. Thieler, E. A. Himmelstoss, J. L. Zichichi, and A. Ergul. “DSAS 4.0 Installation Instructions and User Guide,” in Digital Shoreline Analysis System (DSAS) version 4.0 - An ArcGIS Extension for Calculating Shoreline Change. *U.S. Geological Survey Open-File Report 2008-1278.* 2009.

[11] I. Bagdanavičiūtė, L. Kelpšaitė, and D. Daunys. “Assessment of Shoreline Changes Along the Lithuanian Baltic Sea Coast during the period 1947–2010,” *Baltica*, vol. 25, no. 2, Dec. 2012, pp. 171–184.

[12] M. S. Harris, E. E. Wright, L. Fuqua, and T. P. Tinker. “Comparison of Shoreline Erosion Rates Derived from Multiple Data Types: Data Compilation for Legislated Setback Lines in South Caroline (USA),” *Journal of Coastal Research*, SI 56, pp. 1224–1228 [*10th International Coastal Symposium*, Lisbon, Portugal, 2009].

[13] R development core team. “R: A Language and Environment for Statistical Computing,” *R Foundation for Statistical Computing*, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org. 2010.

[14] V. E. Amaro, F. G. F. Lima, L. R. S. Gomes, A. C. Scudelari, C. F. Neves, and D. V. Busman. “Multitemporal Analysis of Coastal Erosion Based On Multisource Satellite Images, Ponta Negra Beach, Natal City, Northeast Brazil,” in *The 11th Inter. Symp. for GIS and Computer Cartography for Coastal Zone Management*, Victoria, Canada, 2013, pp. 10–14.

Débora V. Busman has received B.Sc. degree in Oceanography from Federal University of Pará, Brazil, in 2004. M. Sc. Degree in Physical, Chemical and Geological Oceanography from Federal University of Rio Grande Foundation, Brazil, in 2006. She is Ph.D. student from Federal University of Rio Grande do Norte (FURN), city of Natal, Brazil.

Venerando E. Amaro has received B.Sc. degree in Geology from Federal University of Mato Grosso, Brazil, in 1986. M. Sc. Degree in Economic Geology from University of Brasília, Brazil, in 1989 and Ph.D. degree in Economic Geology and Hydrogeology from University of São Paulo, Brazil, in 1998. He is currently an Associate Professor in Geoprocessing Laboratory, Department of Geology from FURN, Brazil.

Mattheus da C. Prudêncio is a B.Sc. student in Geology from FURN, Brazil.