Monitoring Shoreline Changes in the North Coast of Puerto Rico in Response to Hard Structures Using Remote Sensing Techniques

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ABSTRACT. — Shorelines are active settings where most of the global habitants live near it. The use of Remote Sensing for shoreline changes through selected years is applied in this study. The tools used to delineate the shoreline variation were supervised and unsupervised classification in addition with ROI polygon and lines in ENVI software. The main purpose of this project is assessing how human structures help mitigate or affect erosion and deposition in Balneario de Carolina area and Arecibo bay area. Satellite image of IKONOS (2001) and aerial photograph (2010) were selected for the shoreline changes analysis in the selected beaches of the north coast of Puerto Rico.

KEYWORDS- *Coastal geomorphology, deposition, erosion, hard structures, IKONOS, remote sensing, shoreline changes*

INTRODUCTION

Shoreline is subjected to continuous change due to natural causes and human interventions in coastal zone. (Kumar et. al., 2010). Shorelines are dynamic environments in constant change. Coastal areas are subject to a variety of phenomena, such as sea level variations, storm surges, wave energy, tidal inundation, tectonics and land subsidence, sediment budget changes, human activities that continually modify and play fundamental roles in coastal development and exposed to erosion (Aiello, Canora, Pasquariello, Spilotro 2013).

Sediments deposition or erosion have important effects in the dynamics of the shorelines. If the sediment patterns are affected so is the morphology of the beach and the coast. Manmade structures can affect the sediment behavior (deposition or erosion). The problem of coastal erosion is recognized worldwide (Laborde, 2010). Studies examining long-term and short-term shoreline changes have generally utilized satellite data (Maiti and Bhattacharya, 2009; Ford, 2013) and aerial photographs (Anders and Byrnes, 1991; Kurosawa and Tanaka, 2001; Ford, 2013). In most of the studies shorelines are manually digitized from satellite images (Chen and Rau 1998).

The main purpose of this project is assessing how human structures help mitigate or affect erosion and deposition

in the selected areas. To conduct this assessment IKONOS (2001) image and aerial photograph (2010) were used for the selected areas.

MATERIAL AND METHODS

Study Area

In this study, 2 beaches of the north coast of Puerto Rico were selected. The balneario de Carolina located in the municipality of Carolina in the coordinates latitude:18°26'47.4"N longitude: 66°00'07.6"W (IMAGE 3) and the Arecibo Bay located in the municipality of Arecibo in the coordinates latitude: 18°28'30.3"N longitude: 66°42'07.3"W (IMAGE 4). Both areas have anthropogenic structures impacting positive or negative the sediments behavior in the year 2006.

In Carolina area a project to mitigate erosion was implemented from March 23, 2005 to June 27, 2006 (IMAGE 1).

IMAGE 1. NuShore mitigation system approximately 55 groins installed. Source NuShore LLC. Carolina Project Blog 2006)

In Arecibo Bay a navigational channel with a jetty from a nautical club was close due to sediments deposition. (IMAGE 2).

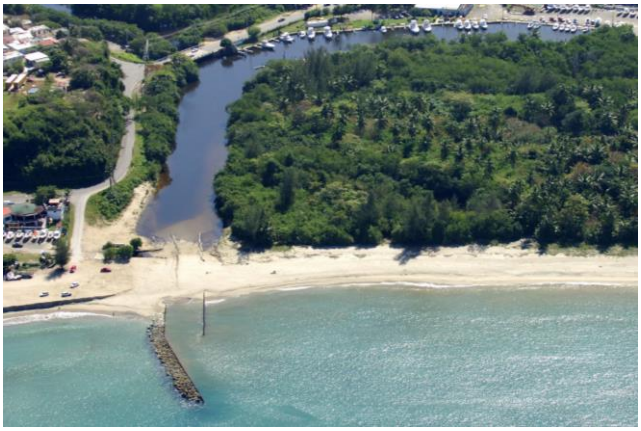

IMAGE 2. Channel close by deposition circa February 13, 2006.
(Source Club Nautico Arecibo 2006)

Dr. Fernando Gilbes from Department of Geology at University of Puerto Rio, Mayagüez, provided satellite images and aerial photography from the selected areas (See Table1).

Image Processing

Shoreline changes were analyzed using a combination of aerial photography and satellite imagery. Satellite image and aerial photograph were selected for the analysis of shoreline changes in the selected beaches of the north coast of Puerto Rico.

TABLE 1. Characteristics of aerial photography and satellite images used for the studied areas.

Year	Type	From
2001	Satellite Image	IKONOS
2010	Aerial Photograph	Airplane

IMAGE 3. Carolina study area (IKONOS 2001)

The selection of the images are due to high spatial resolution of 1 meter to 3 meter and the availability of these ones (no cost). A subset of aerial photography and image was performed using the resize tool from ENVI. The ENVI 5.2 version was used to conduct the supervised, unsupervised classification and for the calculation of erosion and deposition the region of interest (ROI) tool was apply.

The supervised Minimum Distance Classification and the unsupervised Iso Data Classification were used to visualize the shoreline. The unsupervised Iso Data Classification resulted more helpful in delineating the shoreline than the supervised Minimum Distance Classification (FIGURE 1,2,3 and 4). With the unsupervised classification and the image, the shoreline was draw with ROI line in the wet/dry area to delimitate it in both images. Draw a ROI polygon between the difference in lines to calculate the erosion (shortening) or deposition (growing) of the shoreline in square meters (IMAGE 6,8 and TABLE 2).

IMAGE 4. Arecibo study area (IKONOS 2001)

ROI line was drawn to measure the distance between 2001 shoreline and 2010 shoreline in meters (TABLE 2).

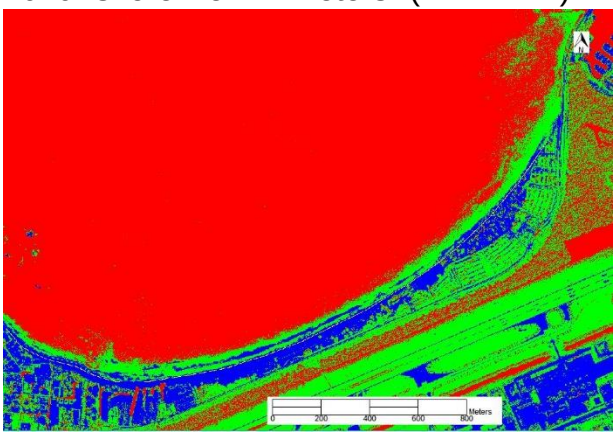

FIGURE 1. Unsupervised Iso Data Classification of Carolina area (2001)

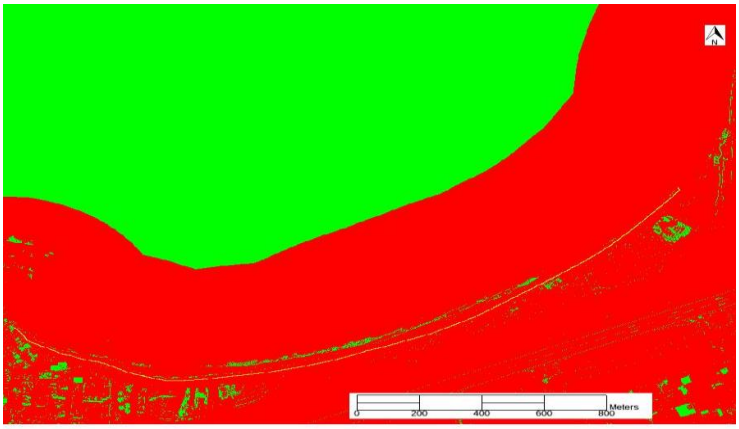

FIGURE 2. Unsupervised Iso Data Classification of Carolina area (2010)

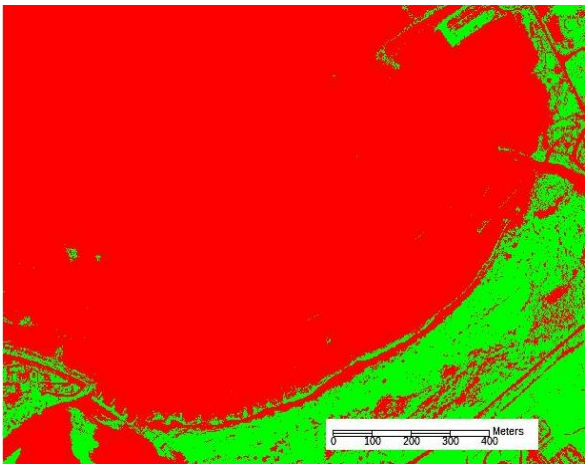

FIGURE 3. Unsupervised Iso Data Classification of Arecibo area (2001)

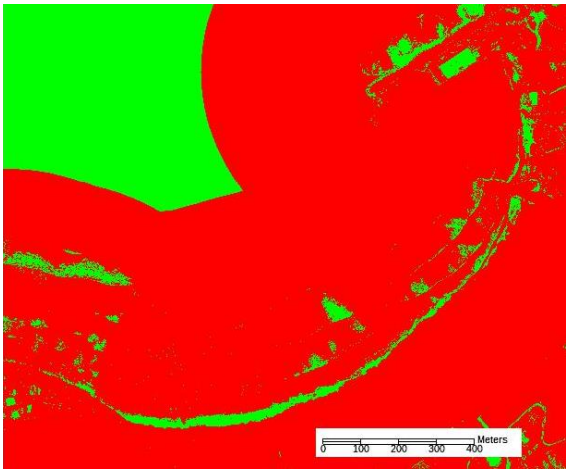

FIGURE 4. Unsupervised Iso Data Classification of Arecibo area (2010)

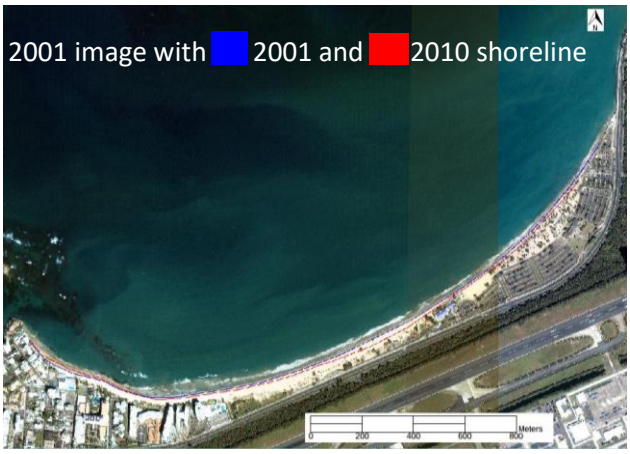

IMAGE 5. Contrast among 2001 and 2010 shoreline in the 2001 Carolina.

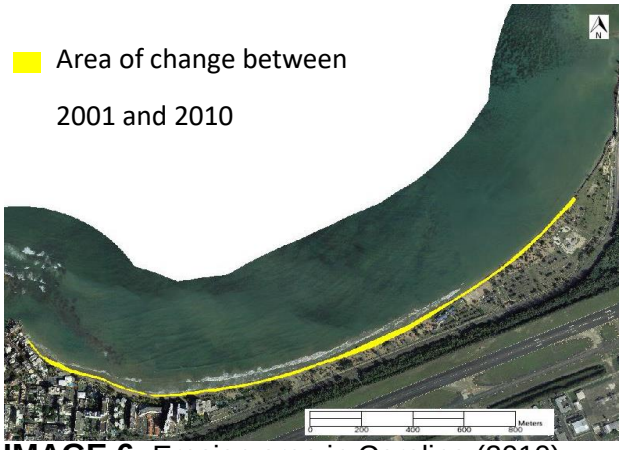

IMAGE 6. Erosion area in Carolina (2010)

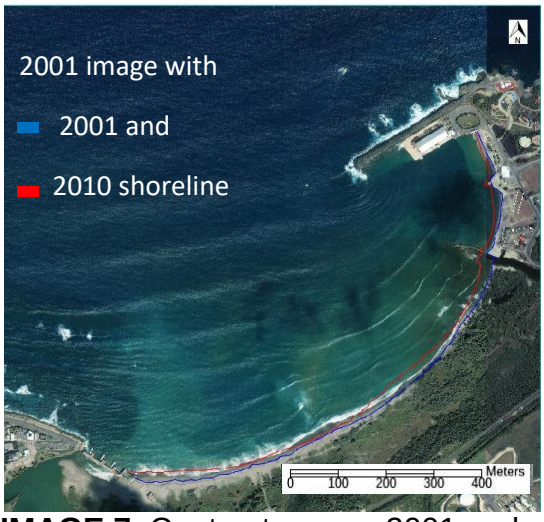

IMAGE 7. Contrast among 2001 and 2010 shoreline in Arecibo area.

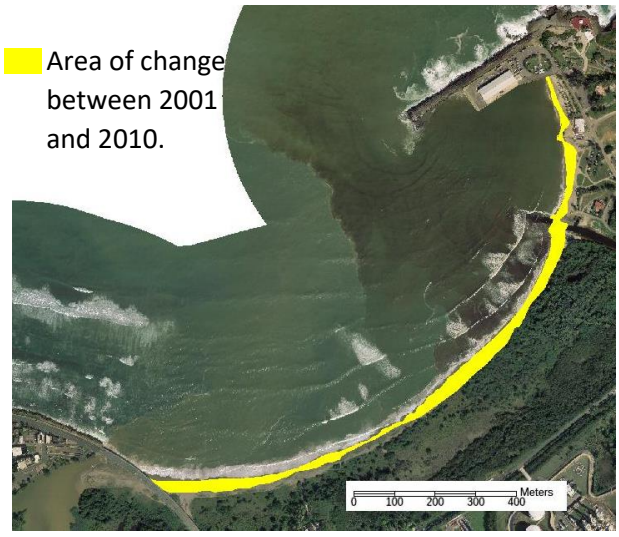

IMAGE 8. Deposition in the shoreline of Arecibo Bay resulting in shoreline growth (2010).

RESULTS AND DISCUSSION

There have been significant changes in both study areas from 2001 to 2010. Erosion in the Balneario de Carolina resulting in shoreline loss. Deposition in the shoreline of Arecibo Bay resulting in shoreline growth (See TABLE 2). Both areas have one tendency erosion or accretion while in other areas this two behavior can be seeing together. The sediments eroded from one side are deposit on the other side.

Carolina Area

Based on the analysis and measures the Balneario de Carolina present erosion. The measure with the highest shoreline loss (erosion) is 20 meters. The lowest measure of shoreline loss is 2 meters. A pattern of erosion cannot be determined at this moment. Further investigation and field visit are required for such conclusions.

Table 2. Shoreline change from 2001 to 2010 data measure with Region of Interest Polygon (m^2) and line (m) tool.

Location	Years	Distance	Area m^2	Results
Carolina	2001-2010	20m to 2m	23,907	Erosion (loss)
Arecibo	2001-2010	31m to 2.5m	68,639	Deposition (grow)

Evidently the erosion is in all the Balneario with the highest point at the center. Accretion areas are not present in the Balneario base on the shoreline comparison. Approximately 23,907 square meters of shoreline loss between 2001 and 2010. As seeing on IMAGE 5 and 6.

Arecibo Area

Based on the analysis and measures the Arecibo Bay have growth (accretion/deposition). The measure with the highest shoreline deposition is 31 meters. The lowest measure of shoreline deposition is 2.5 meters. This growing has been in all the shoreline according to the delineated lines. Approximately 68,639 square meters of shoreline growth. As seeing on IMAGE 7 and 8

CONCLUSIONS

Overall, the ROI tool prove to work measuring the shoreline changes. The Carolina area resulted with a big loss of shoreline. While Arecibo bay on the contrary presented shoreline growth.

The information and results acquired for both study areas can't be related or associated with the hard man made structures as proposed. This is due to the difference in years between the events and the

high resolution images acquired at no cost. Base on the information obtained from the evaluation of the images is not possible to determine if the NuShore mitigation implemented in the Carolina Area was effective or not.

The study events occur circa 2006 and the images available used are from 2001 and 2010.

Based on this: The influence of human activities on rates of shoreline movement may result in either erosion or beach progradation. It is well-documented that structures such as groins and jetties result in progradation on the updrift side of the structure and erosion on the downdrift side (Coastal Engineering Research Center, 1984). The expected results were others.

RECOMMENDATIONS AND LIMITATIONS

Since we experienced a data gap more images from before and after the events are recommended for future research and comprehensive assessment of the selected zones in the study areas.

The date and time of the satellite's images are unknow therefore is unknow if they were taken on high or low tide and if they were in winter (where naturally accumulation occur) or in summer (where the reservoir of sand moves from the foreshore to the longshore and it may look as erosion).

Exploring other ENVI tools for shoreline change analysis to see if they are more efficient than the one used in the project. Example: The Neural Network classification

Images with this resolution are expensive and few of them are available this explain the span of year 2001 and 2010.

Multi spectral images for all the years instead of aerial photograph and images.

Expand the research to surrounding areas such as up currents and down currents of the Balneario de Carolina and Arecibo bay.

Compare the use of the wet and dry boundary with other shoreline delineation techniques.

Try to establish a correlation with Arecibo bay shoreline growth with the rainfall and Rio Grande de Arecibo sediment discharges.

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