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Shoreline Analysis of Beaches in or near Yabucoa, Puerto Rico

Before and After Hurricane Maria

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I. Abstract

On September 20th, 2017 Hurricane Maria made landfall in Yabucoa, Puerto Rico as a category 4 hurricane with maximum sustained winds of 155 mph (NWS, 2017). This undergraduate research evaluated 6 shorelines (beaches) near or in Yabucoa before and after the hurricane. The beaches in Yabucoa analyzed were Lucia Beach, Guayanes Beach, El Cocal Beach and a beach near Punta Yeguas. The beaches analyzed near Yabucoa were Palmas del Mar in Humacao and Punta Tuna Beach in Maunabo. Aerial photographs of 2010 and 2017 were used for a post Maria analysis. For quantitative results the DSAS extension in ArcGIS was used to create transects and analyze the shorelines. NDVI and Infrared analysis of the areas was also performed. The NDVI values for the areas in 2017 ranged from 0.17 to 0.30 while the values for the areas in 2010 ranged from 0.16 to 0.72. The general shoreline analysis of the beaches in Yabucoa showed a rate of accretion of 0.47 m/yr in Lucia Beach, a rate of accretion of 0.44 m/yr in Guayanes Beach, a rate of erosion of 1.22 m/yr in El Cocal Beach and a rate of erosion of 0.86 m/yr in the beach near Punta Yeguas. The shoreline analysis of beaches near Yabucoa showed a rate of erosion of 1.22 m/yr in Palmas del Mar (Humacao) and a rate of erosion of 0.86 m/yr in Punta Tuna Beach (Maunabo). The DSAS software was able to analyze the shorelines but also gave some abnormal values on its transects.

Keywords: Shoreline, DSAS, Hurricane, Maria, Erosion

II. Introduction:

The first effect of Hurricane Maria on Puerto Rico was reported at around 5:00 am on September 20th as hurricane force winds in Vieques and the eastern half of Puerto Rico (NWS, 2017). At 6:15 am, the eye of Hurricane Maria made landfall within the municipality of Yabucoa and over the course of that day hurricane force winds spread all over the island producing extremely heavy rainfall and flooding as the hurricane moved to the northwest (Figure 1; NWS, 2017). At around 2:00 pm the center of the hurricane moved out of the northwestern Puerto Rico but tropical storm force winds continued overnight across the island (NWS, 2017). In the Southeast region of the island, extreme structural and vegetative damage occurred, for example multiple buildings were partially to fully destroyed and thousands of trees and palm were broken in half (NWS, 2017). East of Fajardo, Wave Heights of more than 20 feet were recorded (Figure 2) (NWS, 2017). According to NWS (2017) "trails of coastal flooding due to storm surge along the southeast coast of Puerto Rico were also observed, which affected roads, homes, marinas and other buildings located along the coast". The areas in the southeast coast that were analyzed were beaches in or near Yabucoa. The beaches in Yabucoa were Lucia Beach, Guayanes Beach, El Cocal Beach and a beach near Punta Yeguas (Figures 3 and 4). The beaches near Yabucoa were Palmas del Mar in Humacao and Punta Tuna Beach in Maunabo.

Shorelines all over the world are retreating in a landward direction, a process called shoreline retreat or shoreline erosion (Pilkey et al., 2009). According to Pilkey et al. (2009) probably 80-85% of the Earth's shorelines are retreating and the major causes of this are sea-level rise, reduction in sand supply to the shoreline by human intervention (damming of rivers, armoring of shorelines and dredging of navigation channels), shoreline engineering, wave energy and storm frequency. Coastal erosion is a widespread and ongoing process in Puerto Rico (Bush et al., 1995). Much of the sandy shoreline of Puerto Rico is in a state of change that includes erosion (Bush et al., 1995). Erosion is just a part of coastal evolution meaning that a beach is simply changing its location (Bush et al., 1995). There is no erosion 'problem' until a structure is built on a shoreline; beach erosion is a common and expected event, not a natural disaster (Bush et al., 1995).



Figure 1. Hurricane Maria Trajectory in Puerto Rico (Almukhtar, et. al, 2017).



Figure 2. Significant Wave height during the month of September, East of Fajardo (NWS, 2017).



Figure 3. Three of the Study Areas in or near Yabucoa, Puerto Rico.



Figure 4. Three of the Study Areas in or near Yabucoa, Puerto Rico.

Construction on the shoreline can affect the very delicate balance between sand supply, beach shape, wave energy, and sea-level rise (Bush et al., 1995). Construction near or on the shoreline can 'reduce the natural flexibility of the beach' and result in increased erosion that threaten those constructions (Bush et al., 1995). Natural shoreline erosion is a common event and is not a threat to the coast but an integral part of coastal evolution; this event does not mean that the beach is disappearing but simply changing its location (Bush et al., 1995). Extreme storms, and their strong winds and waves, can be responsible for very rapid changes (like erosion) to coastlines worldwide (Burvingit, 2017). Methods to "solve" shoreline erosion can cost a lot but include the construction of seawalls, beach nourishment, and relocation or abandonment of buildings (Pilkey et al., 2009).

Rates of erosion vary along the coasts, for example on sandy (as opposed to rocky) shorelines common retreat rates are along 1 m, +/- 0.5 m per year (Pilkey et al., 2009). Very rapid changes to coastlines can be due to extreme storms and their strong winds and waves (Burvingit, 2017). A study by Splinter (2014) shows that erosion volumes per storm were dependent on total energy of that storm and of proceeding storms. The beach response to a sequence of extreme storms can be highly variable (Coco, 2014).

The east coast of Puerto Rico is characterized by short period waves (3-5 seconds) from the east and northeast (Dr. Wilson Ramirez, personal communication). Differences with the north coast are that sand deposits here are larger and, morphologically, the east coast is less indented and has broader headlands (formed from plutonic, volcanic, and sandstone rocks) that are located between broad alluvial plains (Dr. Wilson Ramirez, personal communication). A general accretion was measured from 1969 to 1987 with cases of erosion related to building construction (Dr. Wilson Ramirez, personal communication). The coastline from Punta Tuna to Naguabo is an alternation of rocky headlands that have been partly shaped by marine erosion and valleys of alluvial material that have been worked on by wave action and marine deposition to form broad beach plains (Dr. Wilson Ramirez, personal communication). The eastern end of the island is bordered by a shallow shelf with abundant coral and marine organisms forming carbonate sands with its beaches being a mixture of calcium carbonate grains from offshore and quartz and feldspar and igneous rock material and dark minerals from the land area (Prof. Wilson Ramirez personal communication). Punta Tuna beach has coarse carbonate sand beach with some quartz and igneous rock material while Guayanes beach is rich in magnetite (Prof. Wilson Ramirez personal communication). There is a continuous beach plain from the Palmas del Mar marina at Punta Fraile to Morro de Humacao with its composition being mostly calcium carbonate (Prof. Wilson Ramirez personal communication).

Studies analyzing shoreline changes in Puerto Rico have been done by Thieler et al (2007) in which they used the "Digital Shore-line Analysis System (DSAS)" to study the coastal changes in Rincón over the course of 70 years (1936-2006) and arrived to the conclusion that the erosion in the study area was most likely caused by not only natural but also human induced causes (Thieler et al., 2007). This study also recognized various factors that can affect shoreline evolution: underlying geology, interactions between the bathymetry and waves and/or currents, long-term rise in sea-level and hard stabilization (structures built to reduce waves) along the coast (Thieler et al., 2007). NDVI or Normalized Difference Vegetation Index can be used to measure the vegetation. This index employs the Multi-Spectral Remote Sensing data technique to find Vegetation Index, land cover classification, vegetation, water bodies, open area, scrub area, hilly areas, agricultural area, thick forest, thin forest with few band combinations of the remote sensed data (Meera et al., 2015).

The main goal of this research was to quantify the coastal accretion or erosion that the southeastern part of Puerto Rico suffered after the landfall of hurricane Maria. This investigation is also meant to be a first step in analyzing the effect of the hurricane on the Puerto Rican coasts. The use of ArcGIS and its tool DSAS can be an accessible and cost effective method for conducting these studies.

III. Methodology:

The first step in this project was obtaining aerial photographs for the selected study areas for both before and after hurricane Maria. The before Maria (2010) photos were provided by the EarthExplorer database website, while the after Maria photos were provided by a database created by NOAA. A total of 9 photographs from 2010 and 7 photographs from 2017 were used to cover the study areas. The datum used was NAD 1983 State Plane Puerto Rico and Virgin Islands.

For quantitative results of the shoreline changes the Digital Shore-line Analysis System (DSAS) was used. This is an application of the Geographic Information System (ArcGIS) software (Thieler et al., 2007). It is a free ArcGIS tool with focus on the calculation of rate- of- change statistical analyses (Thieler et al., 2007). The border where the land meets the sea in the photographs was used to create the shoreline shapefile that was used for the analysis. Also, the vegetation of the study areas was analyzed and compared among the images. Once all of the shoreline shapefiles were completed, they were "stacked" to provide a visual representation of their change through the years. In this research DSAS was used to compute shoreline change using methods that provide more quantitative results, transects along the shorelines were created using DSAS and a baseline buffer was generated. All of these were placed in a geodatabase file. These were used to compute the following: shoreline change envelope, net shoreline movement, least of

median squares regression and endpoint rate. These methods are different ways to quantify the shoreline movements. The Net Shoreline Movement (NSM) is associated with the date of only two shoreline as it calculates the distance in meters between the oldest and youngest shorelines (Thieler et al., 2009). The End Point Rate (EPR) reported as meters/years calculates the distance between the oldest and youngest shorelines and divides it by the time passed between them in each transect (Thieler et al., 2009). The Shoreline Change Envelope (SCE) calculates the distance between the farthest shoreline from and the closest to the baseline at each transect (Thieler et al., 2009). Finally the Least of Median Squares Regression is used to determine a regression line (Thieler et al., 2009). After all of these analyses the graphs and maps were created using ArcGIS.

IV. Results and Discussion

The shoreline analysis of the beach near Palmas del Mar, Humacao was done with 51 transects. Figures 5- 6 shows the shapefiles of the individual shorelines while figures 7 show the shorelines along the baseline and transects and their calculations. Figure 8 shows the graphs of the End Point Rate and Net Shoreline Movement calculation of the transects. These calculations gave an average End Point Rate of -1.25 m/yr with a standard deviation of 0.46 m/yr. The average Shoreline Change Envelope that was calculated was 9.09 m with a standard deviation of 3.37 m. The average Net Shoreline Movement given was -9.09 m with a standard deviation of 3.37 m. The average Least of Median Squares Regression calculation was -1.25 m/yr with a standard deviation of 0.46 m/yr. These negative values in EPR, NSM and LMS represent an erosion in the shoreline of the study area. In the study area all of the transects that overlapped the shorelines showed negative End Point Rate, Net Shoreline Movement and Least of Median Squares Regression. The transect that showed the lowest values was transect 2, located northeast of the area. This transect



Figure 5. Shoreline of the Beach Near Palmas del Mar, Humacao, in 2010.



Figure 6. Shoreline of the Beach Near Palmas del Mar, Humacao, in 2017 (post Maria).



Figure 7. Shorelines, Transects and Baseline generated by DSAS of the Beach Near Palmas del Mar, Humacao.







shows an End Point Rate of -2.62 m/yr, a Net Shoreline Movement of -19.03 m and a Least of Median Squares Regression of -2.61 m/yr. The transect that showed the highest values was transect 10 with an EPR of -0.38 m/yr, a NSM of -2.76 m and a LMS of -0.38 m/yr. Figures 9 and 10 shows the beach near Palmas del Mar with the infrared band (Band 4) replacing the red band (Band 1). Figures 11 and 12 show the NDVI analysis of the area on both years. The NDVI values for the 2010 photo ranged from 0.69-0.63 in areas of high vegetation, those areas gave values that ranged from 0.29-0.35 in the 2017 photo. These last four images can be used to better visualize the effect of the Hurricane on the vegetation of the area.

The shoreline analysis of the El Cocal beach, Yabucoa was done with 55 transects. Figures 13 and 14 show the individual shorelines while figures 15 show the shorelines with the baseline and transects and their calculations. Figure 16 shows the End Point Rate and Net Shoreline Movement calculation of the transects. These calculations gave an average End Point Rate of -1.22 m/yr with a standard deviation of 1.11 m/yr. The average Shoreline Change Envelope that was calculated was 9.82 m with a standard deviation of 6.87 m. The average Net Shoreline Movement given was -8.87 m with a standard deviation of 8.08 m. The average Least of Median Squares Regression calculation was -1.21 m/yr with a standard deviation of 1.11 m/yr. These negative values in EPR, NSM and LMS represent an erosion in the shoreline of the study area. Most of the transects in the study area gave negative values and the lowest values can be found on transects 15 and transects 46-49 on the southeastern and northwestern parts of the beach respectively. Transect 15 had an End Point Rate of -2.81 m/yr, a Net Shoreline Movement of -20.39 m and a Least of Median Squares Regression of -2.75 m/s. Transect 48 had an End Point Rate of -3.12 m/yr, a Net Shoreline Movement of -22.64 m and a Least of Median Squares Regression of -3.08 m/yr. The transects which showed positive values of EPR, NSM and LMS



Figure 9. 2010 image of the Beach Near Palmas del Mar, Humacao in infrared.



Figure 10. 2017 (post Maria) image of the Beach Near Palmas del Mar, Humacao in infrared.



Figure 11. 2010 NDVI analysis of the Beach Near Palmas del Mar, Humacao.



Figure 12. 2017 (post Maria) NDVI analysis the Beach Near Palmas del Mar, Humacao.



Figure 13. 2010 Shoreline shapefile of El Cocal beach, Yabucoa.





Figure 14. 2017 (post Maria) Shoreline shapefile of El Cocal beach, Yabucoa.

Figure 15. Shorelines alongside the Transects and Baseline generated by DSAS of El Cocal beach,

Yabucoa.





Figure 16. Graphs of the End Point Rate and Net Shoreline Movement calculation of the transects of El Cocal beach, Yabucoa.

were located mostly at the center of the beach on transects 14 to 24. The transect which showed the highest values was transect 16, this transect gave values of 0.8 m/yr in EPR, 5.78 m in NSM and 0.81 m/yr in LMS. Figures 17 - 18 shows El Cocal beach with the infrared band (Band 4) replacing the red band (Band 1). Figures 19 - 20 shows the NDVI analysis of the area on both years. The NDVI analysis for this area showed similar values, in 2010 the values ranged from 0.25 to 0.28 while in 2017 the values ranged from 0.29 to 0.32. These images show the effect of the vegetation on the 2017 photograph compared to the 2010 pre-Hurricane Maria Photograph.

The shoreline analysis of Guayanes Beach, Yabucoa was done with 78 transects. Figures 21 and 22 show the individual shorelines while figures 23 show the shorelines with the baseline and transects and their calculations. Figure 24 shows the End Point Rate and Net Shoreline Movement calculation of the transects. These calculations gave an average End Point Rate of 0.44 m/yr with a standard deviation of 1.54 m/yr. The average Shoreline Change Envelope that was calculated was 8.23 m with a standard deviation of 8.14 m. The average Net Shoreline Movement given was 3.17 m with a standard deviation of 11.17 m. The average Least of Median Squares Regression calculation was 0.44 m/yr with a standard deviation of 1.54 m/yr. These average positive values represent a general accretion of this particular shoreline. The transects showed an average positive value of all four variables, with some variation between positive and negative transects in the middle part of the beach. The transect which showed the highest values was transect 5 with an End Point Rate of 6 m/yr, a Net Shoreline Movement of 45.86 m and a Least of Median Squares Regression of 45.86 m/yr. This transect, alongside transect 6 can be seen as abnormal values as the area that they cover is influenced by a nearby stream. The largest group of transects that showed negative values was transects 24 to 33. Here the transect with the lowest value is transect 25 with an EPR of -3.56 m/yr, a NSM of -25.81 m and a LMS of -3.49 m/yr. Figures 25



Figure 17. 2010 image of El Cocal beach, Yabucoa in infrared.



Figure 18. 2017 (post Maria) image of El Cocal beach, Yabucoa in infrared.



Figure 19. 2010 NDVI analysis of El Cocal beach, Yabucoa.



Figure 20. 2017 (post Maria) NDVI analysis of El Cocal beach, Yabucoa.



Figure 21. 2010 Shoreline shapefile of Guayanes Beach, Yabucoa.



Figure 22. 2017 (post Maria) Shoreline shapefile of Guayanes Beach, Yabucoa.



Figure 23. Shorelines alongside the Transects and Baseline generated by DSAS of Guayanes Beach, Yabucoa.





Figure 24. Graphs of the End Point Rate and Net Shoreline Movement calculation of the transects of Guayanes Beach, Yabucoa.



Figure 25. 2010 image of Guayanes Beach, Yabucoa in infrared.

and 26 show Guayanes Beach with the infrared band (Band 4) replacing the red band (Band 1) while figures 27 and 28 show the NDVI analysis of the area on both years to represent the changes in vegetative cover. On the west side of the beach the NDVI values were around 0.25, in 2017, and 0.38, in 2010.

The shoreline analysis of Lucia Beach, Yabucoa was done with 60 transects. Figures 29 and 30 show shorelines while figures 31 show the shorelines alongside the baseline and transects and their calculations. Figure 32 shows the End Point Rate and Net Shoreline Movement calculation of the transects. These calculations gave an average End Point Rate of 0.44 m/yr with a standard deviation of 1.54 m/yr. The average Shoreline Change Envelope that was calculated was 4.88 m with a standard deviation of 4.53 m. The average Net Shoreline Movement given was 3.44 m with a standard deviation of 5.73 m. The average Least of Median Squares Regression calculation was 0.48 m/yr with a standard deviation of 0.79 m/yr. These positive values of these variables mean a general pattern of accretion in this beach. Almost all of the transects show positive values with the exception of a small group of transects on the southern part of the shoreline (transects 40 - 50). The transect with the lowest values was transect 47 with an End Point Rate value of -0.93 m/yr, a Net Shoreline Movement of -6.76 m and a Least of Median Squares Regression of -0.93 m/yr. The transect with the highest values was transect 56 on the southern part of the shoreline. This transect has a End Point Rate Value of 2.58 m/yr, a Net Shoreline Movement of 18.72 m and a Least of Median Squares regression of 2.61 m/yr. Figures 33 and 34 shows Lucia Beach with the infrared band (Band 4) replacing the red band (Band 1). Figures 35 and 36 shows the NDVI analysis of the area on both years. These four figures can show a representation of the differences in vegetation on the two dates. The NDVI analysis in Punta Lucia in vegetation close to the coast was around 0.17, in 2017, and around 0.44, in 2010.



Figure 26. 2017 (post Maria) image of Guayanes Beach, Yabucoa in infrared.



Figure 27. 2010 NDVI analysis of Guayanes Beach, Yabucoa.



Figure 28. 2017 (post Maria) NDVI analysis of Guayanes Beach, Yabucoa.



Playa Lucia, Yabucoa - 2010

Figure 29. 2010 Shoreline shapefile of Lucia Beach, Yabucoa.



Playa Lucia, Yabucoa - 2017

Figure 30. 2017 (post Maria) Shoreline shapefile of Lucia Beach, Yabucoa.



Playa Lucia, Yabucoa - Transects

Figure 31. Shorelines alongside the Transects and Baseline generated by DSAS of Lucia Beach, Yabucoa.





Figure 32. Graphs of the End Point Rate and Net Shoreline Movement calculation of the transects of Lucia Beach, Yabucoa.



Playa Lucia, Yabucoa - 2010 Infrared

Figure 33. 2010 image of Lucia Beach, Yabucoa.in infrared.



Figure 34. 2017 (post Maria) image of Lucia Beach, Yabucoa in infrared.



Playa Lucia, Yabucoa - 2010 NDVI

Figure 35. 2010 NDVI analysis of Lucia Beach, Yabucoa.



Figure 36. 2017 (post Maria) NDVI analysis of Lucia Beach, Yabucoa

The shoreline analysis of the beach near Punta Yeguas, Yabucoa was done with 10 transects. Figures 37 and 38 show the shorelines while figures 39 shows the shorelines alongside the baseline and transects and their calculations. Figure 40 shows the End Point Rate and Net Shoreline Movement calculation of the transects. These calculations gave an average End Point Rate of -0.62 m/yr with a standard deviation of 0.87 m/yr. The average Shoreline Change Envelope that was calculated was 4.45 m with a standard deviation of 6.29 m. The average Net Shoreline Movement given was -4.45 m with a standard deviation of 6.29 m. The average Least of Median Squares Regression calculation was -0.62 m/yr with a standard deviation of 0.87 m/yr. These negative values in EPR, NSM and LMS represent an erosion in the shoreline of the study area. Only 2 of the 10 transects in this study area showed positive values, the transect with the highest values was transect 3 on the western part of the area with an End Point Rate of 0.59 m/yr, a Net Shoreline Movement of 4.29 m and a Least of Median Squares Regression of 0.6 m/yr. The transect with the lowest values was transect 10 with an EPR of -1.23 m/yr a NSM of -8.9 and a LMS of -1.23 m/yr. Figures 41 and 42 shows the area with the infrared band (Band 4) replacing the red band (Band 1). Figures 43 and 44 shows the NDVI analysis of the area on both years. The NDVI analysis showed similar values, these ranged from 0.18 to 0.28 in 2017 and from 0.16 to 0.36 in 2010. These figures represent the variation in vegetative cover after Maria.

The shoreline analysis of the beach near Punta Tuna, Maunabo was done with 52 transects. Figures 45 and 46 show the shorelines while figures 47 shows the shorelines along the baseline and transects and their calculations. Figure 48 shows the End Point Rate and Net Shoreline Movement calculation of the transects. These calculations gave an average End Point Rate of -0.86 m/yr with a standard deviation of 0.92 m/yr. The average Shoreline Change Envelope that was calculated was 7.44 m with a standard deviation of 5.29 m. The average Net Shoreline



Figure 37. 2010 Shoreline of the beach near Punta Yeguas, Yabucoa.



Figure 38. 2017 (post Maria) Shoreline of the beach near Punta Yeguas, Yabucoa.

Figure 39. Shorelines along the Transects and Baseline generated by DSAS of the beach near Punta Yeguas, Yabucoa.

Figure 40. Graphs of the End Point Rate and Net Shoreline Movement calculation of the beach near Punta Yeguas, Yabucoa.

Figure 41. 2010 image of the beach near Punta Yeguas, Yabucoa in infrared.

Figure 42. 2017 (post Maria) image of the beach near Punta Yeguas, Yabucoa in infrared.

Figure 43. 2010 NDVI analysis of the beach near Punta Yeguas, Yabucoa.

Figure 44. 2017 (post Maria) NDVI analysis of the beach near Punta Yeguas, Yabucoa.

Figure 45. 2010 Shoreline of the beach near Punta Tuna, Maunabo.

Figure 46. 2017 (post Maria) Shoreline of the beach near Punta Tuna, Maunabo.

Figure 47. Shorelines along the Transects and Baseline generated by DSAS of the beach near Punta Tuna, Maunabo.

Figure 48. Graphs of the End Point Rate and Net Shoreline Movement calculation of the transects of the beach near Punta Tuna, Maunabo.

Figure 49. 2010 image of the beach near Punta Tuna, Maunabo in infrared.

Figure 50. 2017 (post Maria) image of the beach near Punta Tuna, Maunabo in infrared.

Figure 51. 2010 NDVI analysis of the beach near Punta Tuna, Maunabo.

Figure 52. 2017 (post Maria) NDVI analysis of the beach near Punta Tuna, Maunabo.

Movement given was -6.25 m with a standard deviation of 6.67 m. The average Least of Median Squares Regression calculation was -0.86 m/yr with a standard deviation of 0.92 m/yr. These negative values in EPR, NSM and LMS represent an erosion in the shoreline of the study area. Most of the transects showed negative values on these three variables, the transects that showed positive values were mostly located on the northern part of the shoreline and consisted of transects 44 to 52. The transects with the lowest values was transect 3 with an End Point Rate of -2.72 m/yr, an Net Shoreline Movement of -19.74 and a Least of Median Squares Regression of -2.75 m/yr. The transect with the highest values was transect 51 with a 1.04 m/yr EPR value, a 7.56 m NSM value and a 1.04 m/yr LMS value. Figures 49 and 50 shows the beach and part of Punta Tuna with the infrared band (Band 4) replacing the red band (Band 1). Figures 51 -52 shows the NDVI analysis of the area on both years. These figures represent the difference in vegetation on the area. In Punta Tuna the NDVI analysis gave the most contrasting values, values of around 0.19 were found in 2017 and values around 0.50 and reaching to 0.72 were found in 2010.

A general rate of accretion was seen in Lucia Beach and Guayanes Beach while a rate of erosion was seen in El Cocal Beach, the beach near Punta Yeguas, Palmas del Mar and Punta Tuna Beach. In terms of coastal erosion the hurricane played an important role. Winds and waves from the hurricane could have caused sediment transport, erosion and deposition in the study areas. Although Guayanes Beach, for example, a general trend of accretion significant changes in the beach morphology in the western part of the area. The hurricanes heavy winds and rain also contributed to the loss in vegetation. Vegetation near the shore seemed to be ripped out and decaying in the 2017 photos. These plants might have been drowned and/or salt sprayed by the waves and rain or broken or even ripped out of the ground by the hurricane winds. These strong storms can represent a break in the normal coastal evolution that the shorelines normally experience and can be an unexpected danger for the citizens living in those areas.

V. Conclusion

The performed analyses show that from 2010 to 2017 (post-Maria) 4 of the study areas were experiencing a level of erosion while 2 of them experienced a level of accretion. Lucia beach, Yabucoa showed a rate of accretion of 0.47 m/yr, Guayanes Beach, Yabucoa showed a rate of accretion of 0.44 m/yr, El Cocal Beach, Yabucoa showed a rate of erosion of 1.22 m/yr, the beach near Punta Yeguas showed a rate of erosion of 0.86 m/yr. Palmas del Mar, Humacao shoed a rate of erosion of 1.22 m/yr and Punta Tuna Beach, Maunabo showed a rate of erosion of 0.86 m/yr. The DSAS software was generally able to analyze the shorelines but also gave some abnormal values for few transects. Accounting for standard deviation, these values are in range of those given by Thieler et. al. (2007). The effect of the hurricane in shoreline retreat can be seen in all but 2 of these coastlines. As stated by Coco (2014) the beach response to a sequence of extreme storms can be variable but these storms can cause rapid changes in shorelines. The NDVI values given for the areas in 2010 ranged from 0.16 to 0.72 in areas near the shoreline or with visible vegetation, in this same areas the NDVI values given for the areas in 2017 ranged from 0.17 to 0.30. The NDVI analysis generally gave higher values for the areas in 2010 but it showed some inconsistencies with what could be seen in the visible band. The effect of the hurricane on the vegetation of the study areas, this difference in vegetation is most probably caused by salt spray and strong winds.

VI. Acknowledgements

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VIII. Appendices

Transect	EPR	SCE	NSM	LMS
1	0	0	0	0
2	-2.62	19.03	-19.03	-2.61
3	-1.74	12.65	-12.65	-1.73
4	-1.89	13.72	-13.72	-1.88
5	-0.92	6.69	-6.69	-0.93
6	-0.97	7.07	-7.07	-0.97
7	-1.33	9.64	-9.64	-1.33
8	-0.52	3.77	-3.77	-0.51
9	-0.58	4.2	-4.2	-0.58
10	-0.38	2.76	-2.76	-0.38
11	-1.21	8.8	-8.8	-1.23
12	-1.08	7.82	-7.82	-1.07
13	-0.76	5.49	-5.49	-0.75
14	-1.04	7.54	-7.54	-1.04
15	-1.89	13.67	-13.67	-1.88
16	-1.42	10.3	-10.3	-1.43
17	-1.28	9.25	-9.25	-1.28
18	-0.86	6.22	-6.22	-0.87
19	-0.72	5.21	-5.21	-0.73
20	-0.89	6.44	-6.44	-0.9
21	-1.43	10.35	-10.35	-1.43
22	-0.75	5.47	-5.47	-0.75
23	-0.87	6.31	-6.31	-0.87
24	-0.94	6.84	-6.84	-0.93
25	-1.42	10.29	-10.29	-1.43
26	-1.96	14.21	-14.21	-1.96
27	-1.82	13.23	-13.23	-1.8
28	-2.12	15.35	-15.35	-2.14
29	-1.68	12.21	-12.21	-1.66
30	-1.29	9.36	-9.36	-1.28
31	-1.75	12.7	-12.7	-1.73
32	-1.65	11.95	-11.95	-1.66
33	-1.26	9.13	-9.13	-1.28
34	-1.26	9.15	-9.15	-1.28
35	-1.26	9.17	-9.17	-1.28

Table 1. Data given by ArcGIS for the analysis of Palmas del Mar, Humacao.

36	-1.24	9.02	-9.02	-1.23
37	-0.91	6.62	-6.62	-0.9
38	-1.6	11.62	-11.62	-1.6
39	-1.37	9.95	-9.95	-1.38
40	-1.46	10.56	-10.56	-1.48
41	-1.43	10.39	-10.39	-1.43
42	-1.53	11.06	-11.06	-1.54
43	-1.32	9.59	-9.59	-1.33
44	-1.23	8.89	-8.89	-1.23
45	-0.9	6.55	-6.55	-0.9
46	-1.03	7.45	-7.45	-1.04
47	-1.36	9.84	-9.84	-1.38
48	-1.17	8.49	-8.49	-1.15
49	-1.12	8.13	-8.13	-1.11
50	-1.56	11.33	-11.33	-1.54
51	-1.15	8.33	-8.33	-1.15

Table 2. Data given by ArcGIS for the analysis of El Cocal Beach, Yabucoa.

TransectId	EPR	SCE	NSM	LMS
1	0	0	0	0
2	-1.16	8.44	-8.44	-1.15
3	-1.84	13.36	-13.36	-1.8
4	-2.15	15.62	-15.62	-2.14
5	-2	14.49	-14.49	-1.96
6	-1.38	10.04	-10.04	-1.38
7	-1.8	13.05	-13.05	-1.8
8	-2.18	15.82	-15.82	-2.14
9	-1.58	11.48	-11.48	-1.6
10	-1.82	13.23	-13.23	-1.8
11	-1.51	10.98	-10.98	-1.54
12	-1.2	8.71	-8.71	-1.19
13	-2.07	15.04	-15.04	-2.05
14	-2.16	15.64	-15.64	-2.14
15	-2.81	20.39	-20.39	-2.75
16	0.8	5.78	5.78	0.81
17	-0.01	0.05	-0.05	0
18	-0.16	1.18	-1.18	-0.16
19	0.36	2.61	2.61	0.36

20	0	0.02	0.02	0
21	0.83	5.99	5.99	0.84
22	0.13	0.92	0.92	0.12
23	0.79	5.73	5.73	0.78
24	0.64	4.64	4.64	0.65
25	-0.27	1.94	-1.94	-0.27
26	-0.37	2.69	-2.69	-0.36
27	-0.6	4.32	-4.32	-0.6
28	-0.49	3.58	-3.58	-0.49
29	-0.35	2.52	-2.52	-0.34
30	-0.81	5.88	-5.88	-0.81
31	-0.12	0.88	-0.88	-0.12
32	0.07	0.52	0.52	0.07
33	-0.42	3.02	-3.02	-0.42
34	-0.65	4.69	-4.69	-0.65
35	-0.44	3.2	-3.2	-0.45
36	-0.86	6.24	-6.24	-0.87
37	-0.58	4.21	-4.21	-0.58
38	-0.69	5.04	-5.04	-0.7
39	-1.99	14.43	-14.43	-1.96
40	-1.89	13.72	-13.72	-1.88
41	-1.68	12.16	-12.16	-1.66
42	-1.38	9.99	-9.99	-1.38
43	-1.29	9.37	-9.37	-1.28
44	-1.55	11.21	-11.21	-1.54
45	-2.16	15.64	-15.64	-2.14
46	-3.11	22.54	-22.54	-3.08
47	-2.9	21.03	-21.03	-2.9
48	-3.12	22.64	-22.64	-3.08
49	-3.03	21.98	-21.98	-3.08
50	-2.73	19.77	-19.77	-2.75
51	-2.17	15.75	-15.75	-2.14
52	-2.66	19.26	-19.26	-2.61
53	-2.67	19.36	-19.36	-2.61
54	-2.58	18.68	-18.68	-2.61
55	-1.47	10.66	-10.66	-1.48

TransectId	EPR	SCE	NSM	LMS
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	6.32	45.86	45.86	6.31
6	4.18	30.32	30.32	4.29
7	3.25	23.6	23.6	3.27
8	2.72	19.73	19.73	2.75
9	2.48	17.98	17.98	2.48
10	2.09	15.13	15.13	2.05
11	1.76	12.79	12.79	1.73
12	2.8	20.3	20.3	2.75
13	2.8	20.33	20.33	2.75
14	0	0	0	0
15	0	0	0	0
16	-0.58	4.24	-4.24	-0.58
17	0.85	6.16	6.16	0.84
18	1.49	10.84	10.84	1.48
19	1.18	8.55	8.55	1.19
20	0.34	2.49	2.49	0.34
21	0.15	1.07	1.07	0.14
22	-0.1	0.69	-0.69	-0.09
23	-0.11	0.83	-0.83	-0.12
24	-1.27	9.21	-9.21	-1.28
25	-3.56	25.81	-25.81	-3.49
26	0	0	0	0
27	-1.66	12.01	-12.01	-1.66
28	-1.9	13.79	-13.79	-1.88
29	-0.83	5.99	-5.99	-0.84
30	0.13	0.96	0.96	0.14
31	-1.72	12.48	-12.48	-1.73
32	-2.19	15.88	-15.88	-2.14
33	-1.93	14	-14	-1.96
34	0.44	3.21	3.21	0.45
35	0.52	3.77	3.77	0.51
36	-0.07	0.48	-0.48	-0.07
37	1.08	7.8	7.8	1.07
38	1.57	11.38	11.38	1.54

Table 3. Data given by ArcGIS for the analysis of Guayanes Beach, Yabucoa.

39	0.08	0.57	0.57	0.07
40	0.88	6.37	6.37	0.87
41	1.96	14.23	14.23	1.96
42	2.04	14.77	14.77	2.05
43	0.62	4.5	4.5	0.62
44	1.06	7.66	7.66	1.07
45	1.22	8.85	8.85	1.23
46	1.45	10.54	10.54	1.43
47	1.05	7.59	7.59	1.04
48	-1.85	13.44	-13.44	-1.88
49	-1.3	9.42	-9.42	-1.28
50	-1.32	9.58	-9.58	-1.33
51	-1.71	12.37	-12.37	-1.73
52	-0.86	6.23	-6.23	-0.87
53	-0.54	3.91	-3.91	-0.53
54	-0.14	0.98	-0.98	-0.14
55	-0.4	2.88	-2.88	-0.4
56	-0.62	4.46	-4.46	-0.62
57	-0.06	0.4	-0.4	-0.05
58	1.49	10.78	10.78	1.48
59	2.28	16.56	16.56	2.25
60	2.44	17.68	17.68	2.48
61	0.81	5.91	5.91	0.81
62	0.21	1.49	1.49	0.21
63	-0.58	4.2	-4.2	-0.58
64	-0.96	6.98	-6.98	-0.97
65	-0.61	4.42	-4.42	-0.6
66	0.17	1.24	1.24	0.18
67	0.31	2.25	2.25	0.31
68	0.04	0.32	0.32	0.05
69	0.85	6.19	6.19	0.84
70	0.01	0.08	0.08	0.02
71	-0.36	2.64	-2.64	-0.36
72	0.12	0.84	0.84	0.12
73	0.8	5.78	5.78	0.81
74	0.88	6.38	6.38	0.87
75	1.42	10.32	10.32	1.43
76	1.62	11.72	11.72	1.6
77	1.37	9.95	9.95	1.38
78	0	0	0	0
1	1	1	1	

TransectId	EPR	SCE	NSM	LMS
1	1.58	11.48	11.48	1.6
2	0.17	1.22	1.22	0.18
3	-0.22	1.59	-1.59	-0.21
4	0.74	5.39	5.39	0.75
5	-0.14	1.03	-1.03	-0.14
6	0.89	6.42	6.42	0.9
7	0.28	2.01	2.01	0.27
8	0.5	3.65	3.65	0.51
9	0.19	1.41	1.41	0.19
10	-0.24	1.77	-1.77	-0.25
11	0.51	3.73	3.73	0.51
12	0.17	1.23	1.23	0.18
13	0.42	3.07	3.07	0.42
14	0.64	4.63	4.63	0.65
15	0.52	3.79	3.79	0.53
16	0.36	2.6	2.6	0.36
17	0.06	0.47	0.47	0.07
18	-0.02	0.15	-0.15	-0.02
19	0.06	0.47	0.47	0.07
20	0.79	5.71	5.71	0.78
21	0.79	5.75	5.75	0.78
22	0.48	3.47	3.47	0.49
23	0.99	7.16	7.16	1
24	1.15	8.35	8.35	1.15
25	1.24	8.98	8.98	1.23
26	0.65	4.73	4.73	0.65
27	1.21	8.76	8.76	1.19
28	1	7.26	7.26	1
29	0.82	5.97	5.97	0.81
30	0.33	2.4	2.4	0.32
31	0.24	1.77	1.77	0.25
32	-0.06	0.47	-0.47	-0.07
33	0.74	5.4	5.4	0.75
34	0.41	2.99	2.99	0.4
35	0.29	2.1	2.1	0.29
36	0.22	1.63	1.63	0.23
37	-0.15	1.07	-1.07	-0.14
38	0.31	2.26	2.26	0.31

Table 4. Data given by ArcGIS for the analysis of Lucia Beach, Yabucoa

39	0.78	5.68	5.68	0.78
40	-0.36	2.63	-2.63	-0.36
41	-0.87	6.34	-6.34	-0.87
42	0	0.02	0.02	0
43	-0.13	0.91	-0.91	-0.12
44	0.08	0.58	0.58	0.09
45	-0.39	2.84	-2.84	-0.38
46	-0.31	2.28	-2.28	-0.31
47	-0.93	6.76	-6.76	-0.93
48	-0.83	6.03	-6.03	-0.84
49	-0.76	5.54	-5.54	-0.75
50	-0.58	4.2	-4.2	-0.58
51	0.09	0.68	0.68	0.09
52	0.29	2.08	2.08	0.29
53	0.29	2.1	2.1	0.29
54	1	7.22	7.22	1
55	1.69	12.27	12.27	1.66
56	2.58	18.72	18.72	2.61
57	2.08	15.1	15.1	2.05
58	2.4	17.39	17.39	2.36
59	2.03	14.71	14.71	2.05
60	2.33	16.91	16.91	2.36

Table 5. Data given by ArcGIS for the analysis of Tuna Beach, Maunabo.

TransectId	EPR	SCE	NSM	LMS
1	0	0	0	0
2	-1.35	9.82	-9.82	-1.38
3	-2.72	19.74	-19.74	-2.75
4	-1.94	14.08	-14.08	-1.96
5	-1.57	11.42	-11.42	-1.6
6	-1.52	10.99	-10.99	-1.54
7	-1.69	12.23	-12.23	-1.66
8	-1.83	13.25	-13.25	-1.8
9	-2.14	15.55	-15.55	-2.14
10	-2.05	14.84	-14.84	-2.05
11	-2.24	16.25	-16.25	-2.25
12	-1.94	14.06	-14.06	-1.96
13	-2.04	14.79	-14.79	-2.05

14	-1.71	12.39	-12.39	-1.73
15	-1.74	12.61	-12.61	-1.73
16	-1.05	7.6	-7.6	-1.04
17	-1.79	13.01	-13.01	-1.8
18	-1.07	7.75	-7.75	-1.07
19	-0.69	5.03	-5.03	-0.7
20	-1.62	11.75	-11.75	-1.6
21	-1.57	11.37	-11.37	-1.54
22	-1.13	8.19	-8.19	-1.11
23	-0.54	3.94	-3.94	-0.55
24	-0.26	1.9	-1.9	-0.27
25	-0.22	1.58	-1.58	-0.21
26	-0.08	0.55	-0.55	-0.07
27	-0.2	1.45	-1.45	-0.19
28	-0.13	0.97	-0.97	-0.14
29	-1.48	10.71	-10.71	-1.48
30	-1.11	8.06	-8.06	-1.11
31	-1.37	9.92	-9.92	-1.38
32	-1.5	10.88	-10.88	-1.48
33	-0.84	6.08	-6.08	-0.84
34	-0.87	6.32	-6.32	-0.87
35	-1.56	11.33	-11.33	-1.54
36	-1.25	9.06	-9.06	-1.23
37	0.38	2.79	2.79	0.38
38	-0.05	0.38	-0.38	-0.05
39	-0.36	2.62	-2.62	-0.36
40	-0.62	4.53	-4.53	-0.62
41	0.05	0.35	0.35	0.05
42	-0.89	6.43	-6.43	-0.9
43	-0.35	2.54	-2.54	-0.34
44	0.01	0.05	0.05	0
45	0.31	2.26	2.26	0.31
46	0.04	0.32	0.32	0.05
47	0.07	0.48	0.48	0.07
48	0.24	1.74	1.74	0.23
49	0.92	6.65	6.65	0.93
50	0.52	3.74	3.74	0.51
51	1.04	7.56	7.56	1.04
52	0.67	4.83	4.83	0.67

TransectId	EPR	SCE	NSM	LMS
1	0	0	0	0
2	0.47	3.44	3.44	0.47
3	0.59	4.29	4.29	0.6
4	-0.07	0.51	-0.51	-0.07
5	-0.31	2.22	-2.22	-0.31
6	-0.4	2.88	-2.88	-0.4
7	-0.58	4.24	-4.24	-0.58
8	-0.52	3.79	-3.79	-0.53
9	-0.81	5.87	-5.87	-0.81
10	-1.23	8.9	-8.9	-1.23

Table 6. Data given by ArcGIS for the analysis of the beach near Punta Yeguas.